Addendum to April 1, 1994
Corrective Measures Implementation
Proposed Alternative Capping System Report

Prepared for

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Reading, Pennsylvania

Prepared by

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May 1994

QUALITY ◊ INTEGRITY ◊ CREATIVITY ◊ RESPONSIVENESS

RUST ENVIRONMENT & INFRASTRUCTURE

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1.0 INTRODUCTION

NGK Metals Corporation submitted an initial report to the U.S. EPA on April 1, 1994, regarding alternative capping systems in lieu of the ROD selected capping systems as specified in the September 30, 1992 Final Decision and Response to Comments issued by U.S. EPA.

Alternative capping systems were proposed for the Pond #1 Area (SWMU #1) Red Mud Disposal Areas and Ponds #2 & #3 Areas (SWMUs #2, 3, 4 and 5) and the drain field area (SWMU #8).

U.S. EPA reviewed NGK's initial report and provided a response in an April 26, 1994 letter. This response stated that insufficient documentation of the assumptions noted in NGK's report was the reason for denying equivalency of the alternative capping systems.

This addendum is written in response to the agency's April 26, 1994 letter and a conference call between U.S. EPA, the Army Corps of Engineers, RUST Environment & Infrastructure and NGK Metals Corporation on April 29, 1994, in which it was agreed to provide the following justification:

1. Applicable regulations noting permeability criteria for synthetic liner systems.

2. U.S. Army Corps of Engineers Hydrologic Evaluation of Landfill Performance (HELP) model calculations showing differences in infiltration or percolation rates. Existing conditions in the Pond #1 Area, the ROD selected alternative and NGK's proposed alternative capping system were to be evaluated.

3. Calculations showing potential infiltration rates from the proposed retention basin for the drain field area in comparison to the Summers Model allowable concentrations based on these infiltration rates.

A May 3, 1994 letter from NGK Metals Corporation summarizing the April 29, 1994, conference call is provided for reference as Attachment 1.

2.0 REGULATORY CITATIONS

A permeability value of $<1 \times 10^{-7}$ cm/sec was specified in the April 1, 1994 Capping System Report for a synthetic liner system; however, this value was not substantiated.

Pennsylvania Hazardous Waste Management Regulations, 25 PA Code, Chapter 264.302(a)(6) states that a cap shall meet the performance requirements specified in Appendix E, Table 3. This table is provided as Attachment 2. The minimum permeability specification for geomembranes is $<1 \times 10^{-7}$ cm/sec for a 50 mil liner.

Although liners themselves if installed with no faulty seams, punctures, or tears are essentially impermeable, the U.S. EPA in its Seminar Publication entitled, "Design and Construction of RCRA/CERCLA Final Covers," dated May 1991, recognizes that liner systems will have flaws as a result of construction and placement activities. Chapter 2 of this document, pages 9-13, included as Attachment 3, provides equations to determine the amount of water flow through a liner. A well constructed liner is considered to have one small hole/acre, equivalent to a flow of 330 gal./day/acre, assuming 12 inches of head. A poorly constructed liner is considered to have 30 holes/acre with an equivalent flow rate of 10,000 gal./day/acre. This information, as it relates to infiltration rates which result in water contact with existing waste materials at the NGK site, is discussed further in Section 4.0.

3.0 HELP MODEL EVALUATION

An evaluation of several scenarios involving the Pond #1 Area was conducted utilizing the U.S. Army Corps of Engineers HELP Model Version 2, April 1, 1992. The model was run to calculate potential percolation rates (infiltration rates) into the existing waste material contained below the Pond #1 Area as denoted on Figure 1.

Four different scenarios were evaluated in this report:

1. Existing Conditions

2. ROD Selected Alternative

3. NGK Proposed Alternative

4. NGK Proposed Alternative - Variant 1

Each scenario is discussed in the sections that follow with the assumptions utilized for model input and output stated.

3.1 EXISTING SITE CONDITIONS

Input and output assumptions for this scenario are as follows:

1. Default rainfall, growing season, temperature and solar radiation data were utilized for Philadelphia, Pennsylvania.

2. The latitude was selected using site specific data of 40° 24′ 09".

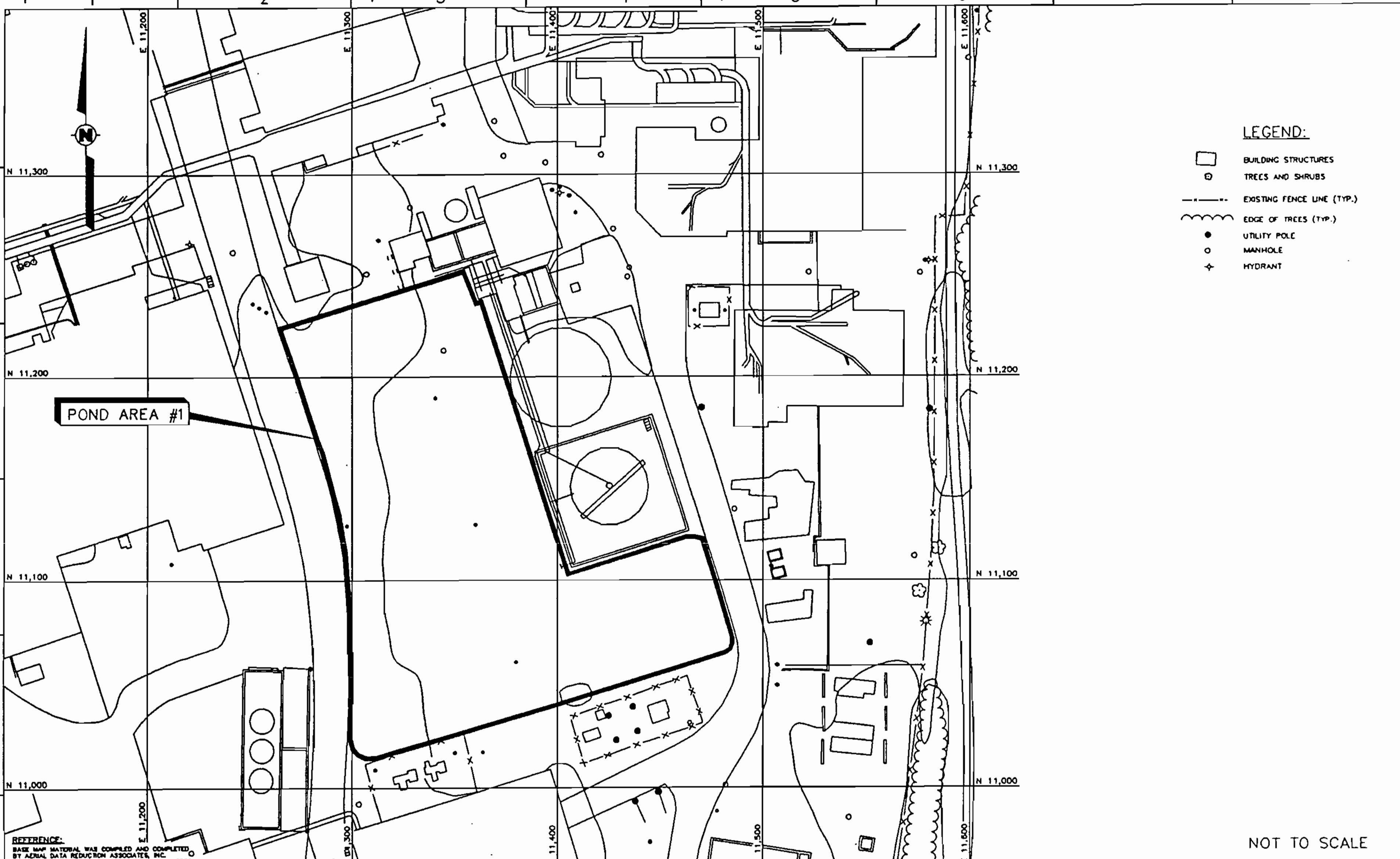
3. Mean monthly rainfall values were selected for a 5-year period (1974-1978 data in model) as the basis for the model.

4. Maximum Leaf Area Index of 0.0 was selected for Bare Ground (gravel is currently present).

5. Evaporative Zone depth of 9.00 inches was selected, equivalent to the Philadelphia, Pennsylvania area for Bare Ground.

6. Soil water content was initialized or selected by the model.

7. One layer was selected as a vertical percolation layer using a soil texture of 1 (see Table 4 provided in Attachment 4). A permeability value of 1 x 10^{-2} cm/sec was associated with material selection.



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DESIGN:		
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FIGURE 1
POND #1 AREA

NGK METALS CORPORATION
READING FACILITY
READING PENNSYLVANIA

RUST ENVIRONMENT & INFRASTRUCTURE

PROJECT NUMBER	35525	DATE 5/10/94	
RUST DWG NUMBER	C-11	FILE NUMBER	
CLIENT DWG NUMBER		SHEET NUMBER	1 OF 3

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PLOT DATE: 5/10/94

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8. The thickness of the layer was 96 inches or 8 feet, which was based on test pit excavation conducted in December of 1993. Waste material was encountered at 8 feet below the existing ground surface. Fill material was evident mixed with some soil to full depth; hence the 1 x 10^{-2} cm/sec permeability selection.

9. Total area of the cover system was provided as 28,315 square feet or 0.65 acres.

10. An SCS Runoff Curve number of 90 was selected for a gravel type surface.

Based on the input and output selected, the average annual totals for precipitation, runoff, evapotranspiration and percolation from Layer 1 were calculated by the model. Output from the model is provided in Attachment 5.

Total annual precipitation was 43.67 inches with an annual percolation of 16.56 inches through Layer 1. This is the amount of infiltrating rain water that in theory would come in contact with the existing waste materials.

Based on peak daily values of runoff compared to precipitation, approximately 50% would result in runoff. Applicable excerpts from the HELP Model Users Guide - April 1992 are provided as Attachment 4 of this document.

3.2 ROD SELECTED ALTERNATIVE

This scenario represents the specified alternative designated by the U.S. EPA Record of Decision. The same assumptions were utilized as in the first scenario with the following exceptions:

1. A total of six layers were specified.

2. Layer 1, the top layer was defined as a 6-inch thick, asphalt vertical percolation layer with a soil texture class of 15. The saturated hydraulic conductivity (permeability) was selected as 7.5 x 10^{-6} cm/sec, equivalent to the average of the Los Angeles County asphalt test samples provided in Attachment 3 in the April 1994 report.

3. Layer 2 was defined as a 6-inch thick gravel subbase material with a soil texture class of 1. The permeability was changed to 1.0 x 10^{-1} cm/sec. This layer was also considered a vertical percolation layer.

4. Layer 3 was defined as a 12-inch thick soil layer with a texture class of 12, silty clay. The permeability was that selected by the model and as specified in Table 4 of Attachment 4. This layer was also considered a vertical percolation layer.

5. Layer 4 was considered a lateral drainage layer equivalent to the 6-inch sand layer in the ROD selected alternative. The texture class selected was 2, with a model

selected permeability of 5.8×10^{-3} cm/sec. The slope of the drainage layer was specified as 1.5% as proposed in the April 1994 report to blend in with the existing roadway and to avoid overtopping the concrete waste treatment tank secondary containment wall. The maximum length of the slope was selected as 100 feet as noted in Figure 2.

6. Layer 5 was defined as a barrier soil liner with a flexible membrane liner. The thickness was specified as 0.05 inches or equal to a 50 mil synthetic liner. The texture class selected was 16, with a model defined permeability of 1×10^{-7} cm/sec. A liner leakage fraction of 0.0005 was selected which is equivalent to 10 holes/acre according to the graph in Figure 5 of Attachment 4. Using the upper bound for a 0.08 cm diameter opening with a K_p of 3.4×10^{-7} cm/sec yields a leakage fraction of 0.001; however, because the Pond #1 Area is only approximately 0.65-acres in size, this fraction was modified to be roughly equivalent to 1 acre or five holes/acre. The model can not distinguish areas less than 1 acre in size.

7. Layer 6 was defined as a vertical percolation layer 96 inches or 8 feet thick similar to Layer 1 in the existing condition scenario presented earlier.

8. An SCS runoff curve number of 98 was selected for an asphalt surface with a modest slope.

Based on the input and output selected, the average annual totals for precipitation, runoff, evapotranspiration and percolation from Layer 6 were calculated by the model. Output from the model is provided as Attachment 5. Total annual precipitation was 43.67 inches with no annual percolation through Layer 6.

Based on the peak daily value for runoff compared to precipitation, approximately 93% of the rainfall would result in runoff.

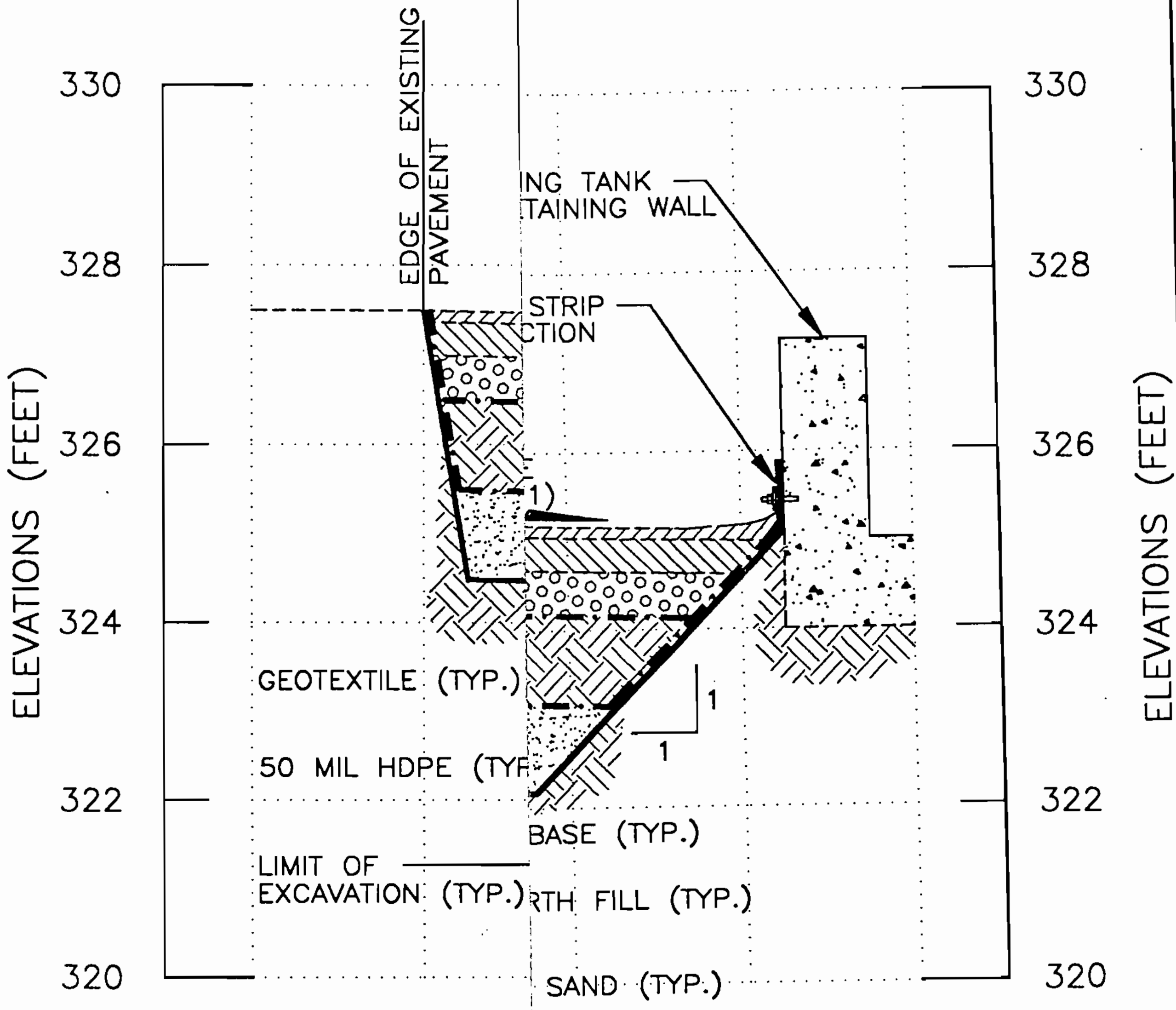
3.3 PROPOSED ALTERNATIVE

This scenario represents the proposed alternative specified in the April 1994 Capping System Report submitted to U.S. EPA on behalf of NGK Metals Corporation. The same assumptions were utilized as in first scenario with the following exceptions:

1. A total of four layers were specified.

2. Layer 1 was selected as a 1.5-inch thick vertical percolation layer equal to the asphalt wearing course. The soil texture selected was 15, using the permeability equal to that derived from the average of the Los Angeles County asphalt permeability of 7.5×10^{-6} cm/sec provided as Attachment 3 in the April 1994 report.

3. Layer 2 was selected as a barrier soil liner with flexible membrane liner with a thickness of 4.5 inches. This was representative of the bituminous concrete base



NOTES

1. PROPOSED SLOPE AND DRA
FROM EXISTING CONDITIONS
PROVIDE PROPER DRAINAGE
2. DEPTH OF EXCAVATION INTO
EXISTING BACKFILL MATERIAL
IS 2.5 TO 3 FEET.

SCALE: 1" = 2'

0 2 4

NO.	REVISIONS

RUST ENVIRONMENT & INFRASTRUCTURE

NUMBER 35525.400

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course asphalt and the emulsified petromat layer. A permeability of 1 x 10^{-7} cm/sec was utilized with a texture class of 16. A leakage rate of 0.0005 was selected as discussed in Section 3.2.

4. Layer 3 was also considered a vertical percolation layer with a thickness of 6 inches, equivalent to the gravel subbase material underlying the asphalt. The texture class was selected as 1, with a permeability of 1 x 10^{-1} cm/sec selected.

5. Layer 4 was selected as a 96-inch thick layer with a texture class of 1. The permeability was selected by the model as 1.0 x 10^{-2} cm/sec. This layer was considered a vertical percolation layer equivalent to the existing condition scenario.

6. An SCS runoff curve number of 98 was selected for an asphaltic surface with a modest slope of 1.5% as proposed in the April 1994 report submitted to the U.S. EPA.

Based on the input and output selected, the average annual totals for precipitation, runoff, evapotranspiration and percolation from Layer 4 were calculated by the model. Output from the HELP model is provided in Attachment 5.

Total annual precipitation was 43.67 inches with an annual percolation rate from Layer 4 of 0.0005 inches. Based on peak daily values of runoff compared to precipitation, approximately 97% would result in runoff.

3.4 PROPOSED ALTERNATIVE-VARIANT 1

One additional scenario was run modeling the alternative cap with a 6-inch asphaltic layer as a soil barrier with a soil texture of 15. The permeability was selected as equal to that determined by Los Angeles County in the April 1994 report. This scenario represents asphalt and an emulsified paving material with an application rate of 0.18 gallons per square yard as one layer. The actual permeability would be less due to the application rate of 0.30 gallons per square yard as proposed in the April 1994 report with a resulting lower infiltration rate.

One additional scenario was run with Layer 1 equaling a 6-inch asphaltic layer with a soil texture of 15 selected. The permeability was selected as equal to that as determined by the Los Angeles County testing performed for RUST Environment & Infrastructure in the April 1994 Capping System Report (3.8 x 10^{-6} cm/sec).

Layer 2 was selected as a gravel drainage layer similar to the ROD specified alternative.

Layer 3 was selected as equivalent to the 96-inch existing condition scenario.

This variation to the proposed alternative resulted in an annual precipitation of 43.67 inches with an annual percolation rate from Layer 3 equivalent to 0.2953 inches. /YKL

Peak daily values of runoff compared to precipitation yielded a value in excess of 96%.

Output from the HELP Model is provided in Attachment 5.

4.0 DRAIN FIELD ASSESSMENT

At the request of U.S. EPA, the Summers Model was used to predict the concentrations of metals expected to leach from contaminated soils and waste materials at various SWMUs at the NGK Metals Corporation site during the RCRA Facility Investigation and Corrective Measures Study.

The model input utilizes an infiltration rate which can be used as an input parameter to yield a concentration in groundwater than can be compared to federal Maximum Contaminant Levels (MCLs) or drinking water standards. The goal is not to exceed any MCL. Infiltration rates have been derived from use of the HELP Model for existing site conditions and the proposed retention basin alternative using an 80 mil HDPE liner. These infiltration or percolation rates in inches/year (as derived from the HELP Model) were used as Qp in the Summers Model equation.

In addition, a comparison is also made using various scenarios of liner leakage rates based on the Giroud and Bonaparte[1] equation for estimating flow rates through holes in synthetic liners. These calculated flow rates are considered the infiltration rates used in the Summers Model to evaluate the proposed retention pond alternative.

4.1 SUMMERS MODEL EVALUATION

The Summers Model is a simple dilution model that predicts chemical concentrations resulting from leaching of a source and mixing of the leachate with the underlying groundwater. The model assumes that a percentage of area rainfall infiltrates the source and generates leachate by desorption of soil contaminants. The resultant chemical concentrations in the leachate are estimated on the basis that the infiltrating water will be in contact with the contaminants for a period of time sufficient for the maximum amount of leaching to occur. It is further assumed that the leachate then mixes completely with groundwater flowing under the source so that the resulting chemical concentration in the groundwater is a simple function of the leachate generation rate, the chemical concentration in the leachate, and the rate of groundwater flow under the source.

The equation that represents the Summers Model used in the assessment is:

$$C_{gw} = (Q_p \times C_p)/(Q_p + Q_{gw})$$

where: C_{gw} = Resultant chemical concentration in groundwater (μg/L)
Q_p = Volumetric flow rate of infiltration into groundwater (ft^3/day)
Q_{gw} = Volumetric flow rate of groundwater under the source (ft^3/day)

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1 Giroud, J.P. and R. Bonaparte, 1989, Leakage through Liners Constructed with Geomembranes - Part 1 - Geomembrane Liners Geotextiles and Geomembranes Volume 8.27-67

C_p = Chemical concentration in the leachate (μg/L).

A value for the variable C_p was the actual EP Toxicity results or was estimated from:

$$C_p = C_s/K_d$$

where: C_s = Chemical concentration in soil (μg/kg)
K_d = Chemical partition coefficient in soil (mg/Kg per mg/L).

In the Summers Model Q_{gw} is estimated on the basis of the application of Darcy's Law to estimate groundwater flow under the areas of concern. The Darcy equation requires the hydraulic conductivity, the hydraulic gradient, and the cross-sectional area of the aquifer under the SWMU area of the land under investigation. These values are known from the analysis of pump tests performed at the NGK site during the RFI and Corrective Measures Study.

A comprehensive Summers Model evaluation was performed by the DUNN Corporation in 1991 which discussed in detail input parameters, pump test derived data, aquifer characteristics, etc. This original report is included with this document as Attachment 6. This 1991 report was accepted by the U.S. EPA as part of the NGK RFI and Corrective Measures Study.

Estimation of Q_p

The amount of leachate generated by a SWMU (Q_p) is the product of the surface area over which contaminated soil occurs times the annual infiltration rate or percolation rate as derived from the HELP Model. The following Giroud and Bonaparte equation was also utilized to generate infiltration rates.

This equation assumes that holes through geomembrane liners are circular in shape and are sufficiently spaced such that leakage through each hole occurs independently from one another. The equation also assumes that the head of liquid ponded above the liner (h) is constant and that the soil that underlies the geomembrane is extremely permeable and offers no resistance to flow through the holes.

q = Flow rate in m^3/sec
C_B = Flow coefficient assumed to be 0.6
a = Area of hole in m^2
g = Acceleration due to gravity of 9.81 m^2/sec
h = head of water above the liner in meters

Estimation of a Value for the Variable K_d

The absorption of inorganics is influenced by clay mineralogy and water chemistry. K_d represents the value of the equilibrium partition coefficient for each inorganic compound.

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The values of K_d were estimated by computing the ratio of the actual soil concentration of the particular inorganic compound (noted during previous site investigations) to the actual value from the EP Toxicity test result from the same soil interval of the same well (also noted during previous site investigations) then averaging the individual values to obtain one K_d value for each inorganic parameter. The following is a list of the computed K_d values for each inorganic parameter of interest.

Average K_d Values for Inorganics

Beryllium	1,500	mg/kg
Cadmium	64	mg/kg
Chromium	4,300	mg/kg
Copper	500	mg/kg
Fluoride	112,500	mg/kg

Estimation of Values for the Variable C_s

The C_s variable represents the concentration of inorganics in the soil. The largest concentration for each inorganic parameter associated with the drain field area was used regardless of depth of the sample or well. The values are noted in Table 1 as soil monitoring results and are expressed in μg/kg.

Results

One of the assumptions inherent in the Summers Model is that the background contamination concentrations are zero in the groundwater underflowing a SWMU. The southeast Red Mud disposal area is situated with respect to the groundwater flow direction upgradient of the drain field area.

The groundwater concentration values calculated from the drain field area are provided in Table 1. The calculated values were compared to the federal MCL values to determine if infiltration or percolation rates calculated would result in exceedance of these MCLs.

The results of the Summers Model and the groundwater evaluation are presented in Table 1. Table 1 presents the soil monitoring results, actual groundwater concentrations, estimated leachate concentrations calculated from the Summers Model, the comparison criteria (MCLs) and a definitive answer on whether the calculated projections made by the model exceed the comparison MCL criteria.

Table 1
Evaluation of Drain Field Data Leachate Concentrations
as Estimated by the Summers Model

Parameter	*Soil Monitoring Results (μg/kg)*	*Estimated Leachate Concentration (μg/L)*		*Actual Groundwater Concentration (μg/L)*	*Federal MCL (μg/L)*	*Are Federal MCLs Exceeded?*	
		Scen. 1	*Scen. 2*			*Scen. 1*	*Scen. 2*
Beryllium	945,000	0.51	5.09	---	4	No	Yes
Cadmium	60,100	0.76	7.59	---	5	No	Yes
Chromium, Total	227,000	0.043	0.43	396	100	No	No
Copper	4,910,000	7.94	79.37	---	1,300	No	No
Fluoride	140,000	0.001	0.01	6.1	2,000	No	No

Table 2
Summers Model Input Parameters

Infiltration (inches/year)	Values derived from HELP Model and Giroud and Bonaparte Equation. See derivations following this table in Sections 4.2 and 4.3.
a = Area of drain field	28,315 ft^2
Precipitation Amount	43.67 inches/year
Q_p =	Drain field precipitation volume in ft^3/day = infiltration rate x drain field area
K =	3.9 ft./day
I =	0.25 ft./day
Q_{gw} =	Groundwater flow under drain field area = 35,197.5 ft^3/year

4.2 CALCULATION OF INFILTRATION RATES USING GIROUD AND BONAPARTE EQUATION

Following are several scenarios with calculated infiltration rates for the proposed retention basin liner system. These infiltration rates are utilized in the Summers Model to generate an estimated leachate concentration for comparison to federal MCLs.

	Scenario 1 1 Foot Head - 1 Hole/Acre Hole Size 0.1 cm^2	*Scenario 2* 1 Foot Head - 10 Holes/Acre Hole Size 0.1 cm^2	*Scenario 3* 5 Foot Head - 1 Hole/Acre Hole Size 0.1 cm^2	*Scenario 4* 5 Foot Head - 10 Holes/Acre Hole Size 0.1 cm^2
Hole Size (m^2)	0.00001	0.00001	0.00001	0.0001
Number of Holes/Acre	1	10	1	10
Head of Water (cm)	30	30	150	150
Rate of Flow (Gals/acre/day)	330	3,300	740	7,400
Infiltration Rate (Rate of Flow x Area) (Gals/day)	214 or 28.68 ft^3/day	2,145 or 286.8 ft^3/day	481 or 64.30 ft^3/day	4,810 or 643.0 ft^3/day

The values utilized in Table 1 for the infiltration rates were based on Scenario 1 and Scenario 2. Ten holes/acre would be considered better than average liner construction while one hole/acre would be considered excellent based on the discussion in Section 3.0.

4.3 CALCULATION OF INFILTRATION RATES USING THE HELP MODEL

Although this was not part of the evaluation as was discussed in the conference call on April 29, 1994, the HELP Model was utilized to derive an infiltration rate or percolation rate for the Summers Model input in addition to the Giroud and Bonaparte equation. The Giroud and Bonaparte equation is felt to be excessively conservative as the underlying soil layer is not considered to retard flow.

Attachment 7 presents the HELP Model output runs for the existing site conditions associated with the drain field area and that of the proposed alternative comprised of an 80 mil HDPE lined retention basin as shown in Figure 3. This was the proposed alternative specified in the April 1994 report.

The existing condition for the drain field area utilized the following input parameters:

1. Default rainfall, growing season, temperature and solar radiation data were utilized for Philadelphia, Pennsylvania.

2. The latitude was selected using site-specific data of 40° 24′ 09″.

3. Mean monthly rainfall values were selected for a 5-year period (1974-1978 data in model) as the basis for the model.

4. Maximum Leaf Area Index of 2.0 was selected for Fair Grass equivalent to the vegetative cover present.

5. Evaporative zone depth of 21.00 inches was selected for Fair Grass for Philadelphia, Pennsylvania.

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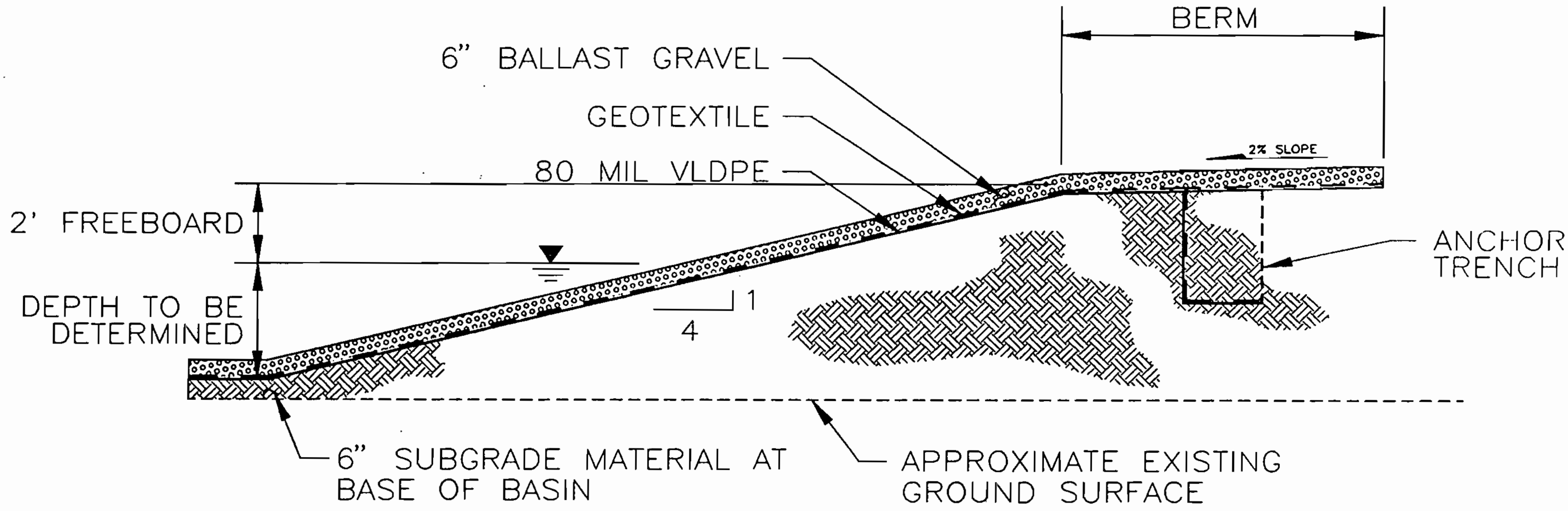

TYPICAL SECTION

NOT TO SCALE

RUST ENVIRONMENT & INFRASTRUCTURE	FIGURE 3 ALTERNATIVE CAPPING SYSTEM DRAIN FIELD AREA
PROJ. NO.: 35525.400 DATE: 5/10/94	NGK METALS CORPORATION READING FACILITY
RUST DWG. NUMBER: C-09	READING PENNSYLVANIA

6. Soil water content was initialized or selected by the model.

7. One layer was selected with an uncompacted thickness of 96 inches. This was based on the average depth from ground surface to the seasonal groundwater table as documented from prior site investigations.

8. The layer was selected as a vertical percolation layer using a soil texture of 1 (see Table 4 included in Attachment 4). A permeability value or saturated hydraulic conductivity value of 1.2×10^{-4} cm/sec was selected.

9. Total area of the cover system was provided as 28,315 square feet or 0.65 acres.

10. An SCS runoff curve number of 75 was selected for a grass type area.

Based on the input and output data selected, the average annual totals for precipitation, run-off, evapotranspiration and percolation from Layer 1 were calculated by the model. Output from the model is provided in Attachment 7.

Total precipitation was 43.67 inches with a percolation value of 9.56 inches. Based on peak daily values of runoff compared to precipitation, approximately 39%. would result in runoff. Applicable excerpts from the HELP Model Users Guide - April 1992 are provided as Attachment 4 to this document.

The HELP Model was also run for the proposed alternative retention basin as specified in the April 1994 Capping System Report. The same assumptions were utilized for the existing conditions with the following exceptions:

1. A total of three layers were utilized for the model input.

2. Layer 1 was equal to the 6-inch pea gravel layer set on top of the synthetic liner. A soil texture of 1 was utilized with the permeability selected at 4 cm/sec. A slope of 1% was selected over a maximum distance of 250 feet. This layer was deemed a lateral drainage layer.

3. Layer 2 was selected as an 0.08-inch thick HDPE liner with a texture class of 17. The model selected permeability was 1×10^{-8} cm/sec. The layer type was selected as 4, a barrier soil liner with flexible membrane liner. A liner leakage fraction of 0.0005 was selected, equivalent to 10 holes/acre over the approximate 0.65-acre area.

4. Layer 3 was input the same as Layer 1 in the existing condition.

5. An SCS runoff curve number of 90 was selected for a gravel-type layer.

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Based on the input and output data selected, the average annual totals for precipitation, runoff, evapotranspiration and percolation from Layer 3 were calculated by the model. Output from the model is provided in Attachment 7.

Total precipitation was 43.67 inches with a percolation value of 0.0001 inches/year.

Based on peak daily values, approximately 72% of the rainfall would result in runoff and approximately 19% in lateral drainage. The remainder would evaporate with a resulting no flow condition through the liner itself.

The average annual value for percolation from Layer 3 of 0.0005 inches equates to roughly 8.8 gallons or 1.18 cubic feet of water over the 0.65-acre area per year. This is substantially less than the 1 hole/acre leakage calculation value using the Giroud and Bonaparte equation. Because this HELP Model generated value is so insignificant, it was not utilized in deriving a Summers Model estimate.

5.0 CONCLUSIONS

A sound regulatory basis for use of the 1 x 10^{-7} cm/sec permeability criteria for a synthetic liner system exists as presented in Section 2.0. This synthetic liner system referenced is believed to be equivalent to the impregnated petromat material with an emulsion application rate of 0.30 gallons/square yard as proposed for use for the Pond #1 Area and Red Mud Disposal Areas.

Based on the HELP Model evaluations presented in Section 3.0, the projected amount of infiltration into the Pond #1 Area will be reduced by a factor equal to 33,000 (from over 16 inches to less than 0.0005 inches per year). The difference between the ROD selected alternative percolation rate as compared to the proposed alternative rate is not deemed to be significant, 0.0005 inches/year.

Similar conclusions can be drawn for the proposed alternative capping system for the Red Mud Disposal Area.

Using the Giroud and Bonaparte equation and a 1-foot head of water on top of the proposed 80 mil lined retention basin (serving as a cap over the drain field) through ten holes/acre with circular holes of 0.1 cm^2, a total of 2,145 gallons/day could be generated. This assumes a modest construction quality effort. Using an EPA definition of "excellent" construction with one hole/acre, 214 gallons of water could be generated per day which would percolate through the liner system. Using these values in the Summers Model, only slight exceedances to federal MCLs for beryllium and cadmium were noted using 10 holes/acre. In evaluating the proposed retention basin using the HELP Model, the amount of percolation predicted is over four orders of magnitude less than that derived for Scenario 2 through the Giroud and Bonaparte equation derived value. No exceedances to MCLs are noted using the HELP Model.

In summary, the proposed alternative capping systems will clearly satisfy the intent of the ROD and protect human health and the environment equally as well as the ROD selected alternatives.

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ATTACHMENT 1

NGK BERYLCO

NGK Metals Corporation

P.O. Box 13367 Reading, PA 19612-3367 215 921-5000 Fax 215 921-5358

May 3, 1994

CERTIFIED MAIL

Mr. Vernon Butler, RPM
Corrective Action RCRA Enforcement Section
U.S. Environmental Protection Agency
Region III
841 Chestnut Building
Philadelphia, PA 19107

Re: Initial Administrative Order
EPA Docket No. RCRA-3-067CA
Well Relocation

Dear Mr. Butler:

This letter summarizes our conference call of April 29, 1994. The phone call participants were Tom Broadhurst from the U.S. Army Corps of Engineers; Vernon Butler from the U.S. Environmental Protection Agency (USEPA); Dave Wolfe, Charles Suenkonis, Jeff Holmes, and Chris Stahl from Rust Environment & Infrastructure (RUST); and Lynne Woodside from NGK Metals Corporation. The conversation was based on the NGK's April 1, 1994 Corrective Measures Implementation Proposed Alternative Capping Systems report and the USEPA's letter dated April 26, 1994 responding to the subject report. The following items summarize our conversation of April 29, 1994.

- RUST will provide the USEPA water flow calculations through the various capping scenarios to document permeabilities of the capping systems to show similarity between the ROD selected cap and RUST's proposed cap with a substantial reduction in infiltration throughout materials presently exposed. The US Army Corp of Engineer's Hydraulic Evaluation of Landfill Performance (HELP) Model will be used to evaluate precipitation flowing through three scenarios. Existing conditions, Record of Decision (ROD) selected cap, and the proposed alternative capping system will be evaluated for Pond Area 1. Tom Broadhurst will collaborate with RUST on input parameters prior to running the HELP Model.

- REI will compare flow through the proposed retention basin liner system in the area of the drain field to the Summers Model evaluation for waste leachability impacts to groundwater.

- Documentation of state and federal regulations regarding capping design and permeability requirements will be provided to the USEPA.

USEPA agreed to evaluate the additional information provide by REI and in particular the significant differences between the ROD selected cap and the alternative capping systems proposed by REI. USEPA also agreed that the alternative capping systems if it can be shown to provide no significant differences from the ROD, the alternative capping system will be approved. After the cap design basis has been agreed to, a date for submission of the 50% cap design report will be established.

I certify that the information contained in or accompanying this letter is true, accurate, and complete. As to the portion of this submission for which I cannot personally verify its accuracy, I certify under penalty of law that this submission and all attachments were prepared in accordance with the procedures designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, or the immediate supervisor of such person(s), the information is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fines and imprisonment for knowing violations.

Sincerely,
NGK Metals Corporation

Lynne Woodside

Lynne Woodside
Supervisor, Environmental Affairs

cc: Mr. Frank Thomas
Mr. Charles Suenkonis

ATTACHMENT 2

CHAPTER 2
SOILS USED IN COVER SYSTEMS

INTRODUCTION

This chapter describes several important aspects of soils design for cover systems over waste disposal units and site remediation projects. The chapter focuses on three critical components of the cover system: composite action of soil with a geomembrane liner; design and construction of low hydraulic conductivity layers of compacted soil; and mechanisms by which low hydraulic conductivity layers can be damaged. In addition, types of soils used for liquid drainage or gas collection also will be discussed.

TYPICAL COVER SYSTEMS

Cover systems perform many functions. One of the principal objectives of a cover system is to reduce leaching of contaminants from buried wastes or contaminated soils by minimizing water infiltration. Cover systems also promote good surface drainage and maximize runoff. In addition, they restrict or control gas migration, or, at some sites, enhance gas recovery. Finally, cover systems provide a physical separation between buried wastes or contaminated materials and animals and plant roots. When designing a cover system, all of these requirements, plus others, typically must be considered.

As presented and discussed in Chapter 1, Figures 1-1 and 1-2 illustrate two typical cover profiles (see pages 1-3 and 1-7). Figure 1-1 illustrates the minimum cover profile recommended by EPA for hazardous waste. Many of the layers shown in the figure are composed of soils or have soil components. Each layer has a different purpose and the materials must be selected and the layer designed to perform the intended function:

- *Topsoil* - The topsoil supports vegetation (which minimizes erosion and maximizes evapotranspiration), separates the waste from the surface, stores water that infiltrates the cover system, and protects underlying materials from freezing during winter and from desiccation during dry periods.
- *Filter* - The filter separates the underlying drainage material from the topsoil so that the topsoil will not plug the drainage material. The filter is often a geotextile, but also can be soil.
- *Drainage Layer* - The drainage layer (which is not needed in arid climates) serves to drain away water that infiltrates the topsoil.
- *Geomembrane Liner and Low Hydraulic Conductivity Soil Layer* - The geomembrane and low hydraulic conductivity soil layer form a composite liner that serves as a hydraulic barrier to impede water infiltration through the cover system.

Figure 1-2 illustrates an alternative cover profile recommended by EPA for hazardous waste. In Figure 1-2, *cobbles* are placed on the topsoil to provide protection from erosion. Cobbles, which are normally used only at very arid sites, allow precipitation to infiltrate underlying materials, but do not promote evapotranspiration (since there are no plants present). Figure 1-2 also depicts a *biobarrier* between two filters. The biobarrier is usually a layer of cobbles, approximately 30- to 90-cm (1- to 3-ft) thick. The biobarrier stops animals from burrowing into the ground, and, if the cobbles are dry, prevents the penetration of plant roots. The *gas vent layer* facilitates removal of gases that could accumulate in the waste layer.

The cover profiles shown in Figures 1-1 and 1-2 provide general guidance only. Depending on the specific circumstances at a particular site, some of the layers shown in these figures may not be necessary. For example, at an extremely arid site, a cover system placed over nonhazardous, nonputrescible waste may simply consist of a single layer of topsoil with no drainage layer, no hydraulic barrier, and no gas vent layer. Conversely, some situations may require more layers than those shown in these figures. For example, radioactive waste such as uranium mill tailings may require a radon-emission-barrier layer. In addition, the designer may need to include several components or layers within the cover system to satisfy multiple objectives. When such objectives lead to conflicting technical requirements, tradeoffs are frequently necessary.

FLOW RATES THROUGH LINERS

Figure 2-1 illustrates three types of hydraulic barriers (liners) for cover systems: 1) a low hydraulic conduc-

tivity, compacted soil liner; 2) a geomembrane liner; and 3) a geomembrane/soil composite liner. Flow rates for each of these types of liners are calculated below for the purpose of comparing the effectiveness of the barriers.

Flow rates through *compacted soil liners* are calculated using Darcy's law, the basic equation used to describe the flow of fluids through porous materials. Darcy's law states:

$$q = k_s \, i \, A$$

where q is the flow rate (m^3/s); k_s represents the hydraulic conductivity of the soil (m/s); i is the dimensionless hydraulic gradient; and A is the area (m^2) over which flow occurs. If the soil is saturated and there is no soil suction, the hydraulic gradient (i) is:

$$i = (h + D) / D$$

where the terms are defined in Figure 2-1 (h is the depth of liquid ponded above a liner with thickness D). For example, if 30 cm (1 ft) of water is ponded on a 90-cm (3-ft) thick liner that has a hydraulic conductivity of 1×10^{-9} m/s (1×10^{-7} cm/s), the flow rate is 120 gal (454 L)/acre/day. If the hydraulic conductivity is increased or decreased, the flow rate is changed proportionally (Table 2-1).

The second liner depicted in Figure 2-1 is a *geomembrane liner*. It is assumed that the geomembrane has one or more circular holes (defects) in the liner, that the holes are sufficiently widely spaced that leakage through each hole occurs independently from the other holes, that the head of liquid ponded above the liner (h) is constant, and that the soil that underlies the geomembrane has a very large hydraulic conductivity (the subsoil offers no resistance to flow through a hole in the geomembrane). Giroud and Bonaparte (1) recommend the following equation for estimating flow rates through holes in geomembranes under these assumptions:

$$q = C_B \, a \, (2gh)^{0.5}$$

where q is the rate of flow (m^3/s); C_B is a flow coefficient with a value of approximately 0.6; a is the area (m^2) of a circular hole; g is the acceleration due to gravity (9.81 m/s^2); and h is the head (m) above the liner. For example, if there is a single hole with an area of 1 cm^2 (0.0001 m^2) and the head is 30 cm (1 ft) (0.305 m), the calculated rate of flow is 3,300 gal (12,491 L)/day. If there is one hole per acre, then the flow rate is 3,300 gal (12,491 L)/acre/day.

Flow rates for other circumstances are calculated in Table 2-2. Giroud and Bonaparte report that with good quality control, one hole per acre is typical (1). With poor control, 30 holes per acre is typical. They also note that most defects are small (<0.1 cm^2), but that larger holes are occasionally observed. In calculating the rate of flow for "No Holes" in Table 2-2, it was assumed that any flux of liquid was controlled by water vapor transmission; a

Table 2-1. Calculated Flow Rates through Soil Liners with 30 cm of Water Ponded on the Liner

Hydraulic Conductivity (cm/s)	Rate of Flow (gal/acre/day)[a]
1×10^{-6}	1,200
1×10^{-7}	120
1×10^{-8}	12
1×10^{-9}	1

[a]L = gal x 3.785

Table 2-2. Calculated Flow Rates Through a Geomembrane with a Head of 30 cm of Water above the Geomembrane

Size of Hole (cm^2)	Number of Holes Per Acre	Rate of Flow (gal/acre/day)[a]
No holes	--	0.01
0.1	1	330
0.1	30	10,000
1	1	3,300
1	30	100,000
10	1	33,000

[a]L = gal x 3.785

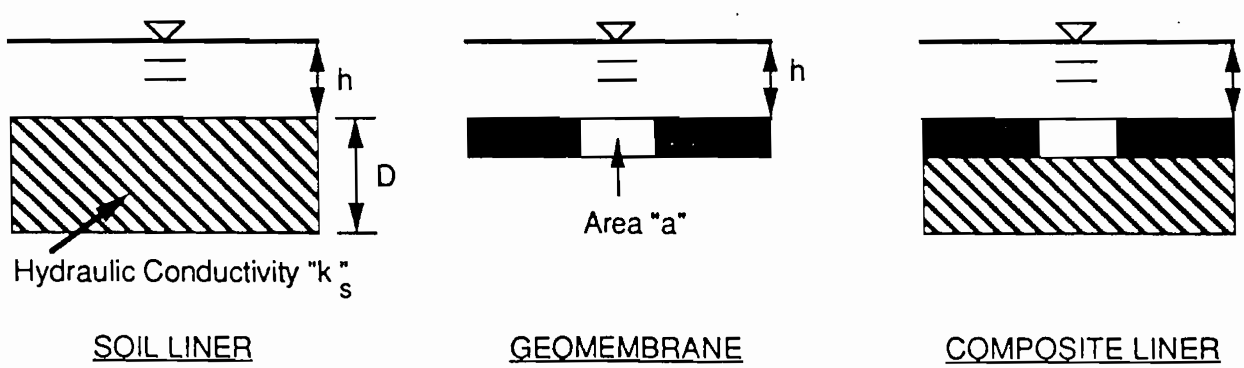

Figure 2-1. Soil liner, geomembrane liner, and composite liner.

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flux of 0.01 gal/acre/day corresponds to a typical water vapor transmission rate of geomembrane liner materials.

The third type of liner depicted in Figure 2-1 is a *composite liner*. Giroud and Bonaparte (2) and Giroud et al. (3) discuss seepage rates through composite liners. They recommend the following equation for computing seepage rates for cases in which the hydraulic seal between the geomembrane and soil is poor:

$$q = 1.15\, h^{0.9}\, a^{0.1}\, k_s 0.74$$

where all the parameters and units are as indicated previously. This equation assumes that the hydraulic gradient through the soil is 1. If there is a good hydraulic seal between the geomembrane liner and underlying soil, the flow rate is approximately one-fifth the value computed from the equation shown above; the constant in the equation is 0.21 rather than 1.15 for the case of a good seal. For example, suppose the geomembrane component of a composite liner has one hole/acre with an area of 1 cm^2 per hole, the hydraulic conductivity of the subsoil is 1×10^{-7} cm/s (1×10^{-9} m/s), the head of water is 30 cm (1 ft) and a poor seal exists between the geomembrane and soil. The calculated flow rate is 0.8 gal (3 L)/acre/day. Table 2-3 shows other calculated flow rates for composite liners with a head of water of 30 cm (1 ft.)

It is useful to compare the three types of liners under a variety of assumed conditions, as illustrated in Table 2-4. For discussion purposes, each liner type is classified as poor, good, or excellent. EPA requires that low permeability compacted soil liners used for hazardous wastes have a hydraulic conductivity no greater than 1×10^{-7} cm/s; therefore, a soil liner with a hydraulic conductivity of 1×10^{-7} cm/s is described in Table 2-4 as a "good" liner. A compacted soil liner with a 10-fold higher hydraulic conductivity is described as a "poor" liner, and a soil liner with a 10-fold lower hydraulic conductivity is described as an "excellent" liner.

For geomembrane liners, a liner with a large number of small holes (30 holes/acre, with each hole having an area of 0.1 cm^2) is described as a "poor" liner because Giroud and Bonaparte suggest that such a large number of defects would be expected only with minimal construction quality control (1). A "good" geomembrane liner was assumed to have been constructed with good quality assurance and an "excellent" geomembrane liner was assumed to have one small hole/acre (1). For all of the seepage rates computed for composite liners in Table 2-4, it was assumed that there was poor contact between the geomembrane and soil.

As Table 2-4 illustrates, a composite liner (even one built by poor to mediocre standards) significantly outperforms a soil liner or a geomembrane liner alone. For this reason, a composite liner is recommended when there is enough rainfall to warrant a very low-permeability hydraulic barrier in the cover system.

Table 2-3. Calculated Flow Rates for Composite Liners with a Head of Water of 30 cm

Hydraulic Conductivity of Subsoil (cm/s)	Size of Hole in Geomembrane (cm^2)	Number of Holes/Acre	Rate of Flow (gal/acre/day)[a]
1×10^{-6}	0.1	1	3
1×10^{-6}	0.1	30	102
1×10^{-6}	1	1	4
1×10^{-6}	1	30	130
1×10^{-6}	10	1	5
1×10^{-7}	0.1	1	0.6
1×10^{-7}	0.1	30	19
1×10^{-7}	1	1	0.8
1×10^{-7}	1	30	24
1×10^{-7}	10	1	1.0
1×10^{-8}	0.1	1	0.1
1×10^{-8}	0.1	30	3
1×10^{-8}	1	1	0.1
1×10^{-8}	1	30	4
1×10^{-8}	10	1	0.2
1×10^{-9}	0.1	1	0.2
1×10^{-9}	0.1	30	0.6
1×10^{-9}	1	1	0.03
1×10^{-9}	1	30	0.8
1×10^{-9}	10	1	0.03

[a] L = gal x 3.785

To maximize the effectiveness of a composite liner, the geomembrane must be placed to achieve a good hydraulic seal with the underlying layer of low hydraulic conductivity soil. As shown in Figure 2-2, the composite liner works by limiting the flow of fluid in the soil to a very small area. Fluid must not be allowed to spread laterally along the interface between the geomembrane and soil. To ensure good hydraulic contact, the soil liner should be smooth-rolled with a steel-drummed roller before the geomembrane is placed, and the geomembrane should have a minimum number of wrinkles when it is finally covered. In addition, high-permeability material, such as a sand bedding layer or geotextile, should not be placed between the geomembrane and low hydraulic conductivity soil (Figure 2-2) because this will destroy the composite action of the two materials.

If there are concerns that rocks or stones in the soil material may punch holes in the geomembrane, the stones should be removed, or a stone-free material with a low hydraulic conductivity placed on the surface. Vibratory screens also can be used to sieve stones prior to placement. Alternatively, mechanical devices that sieve stones or move them to a row in a loose lift of soil may be used. A different material, or a differently

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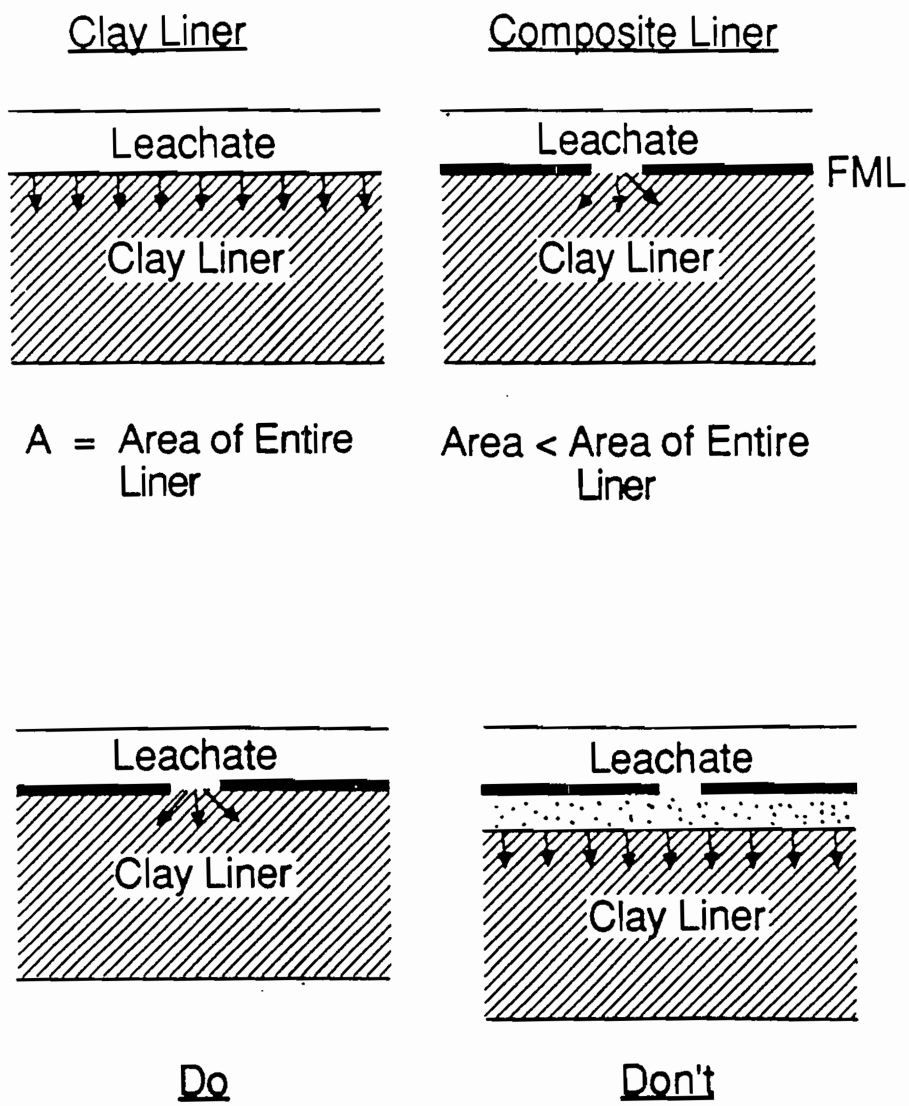

Figure 2-2. Soil liner and composite liner.

processed material that has fewer and smaller stones, may be used to construct the uppermost lift of the soil liner (i.e., the lift that will serve as a foundation for the geomembrane).

CRITICAL PARAMETERS FOR SOIL LINERS

Materials

The primary requirement for a soil liner material is that it be capable of being compacted to produce a suitably low hydraulic conductivity. To meet this requirement, the following conditions should be met:

- *Fines* - The soil should contain at least 20 percent fines (fines are defined as the percentage, on a dry-weight basis, of material passing the No. 200 sieve, which has openings of 0.075 mm).
- *Plasticity Index* - The soil should have a plasticity index of at least 10 percent, although some soils with a slightly lower plasticity index may be suitable. Soils with plasticity indices less than about 10 percent have very little clay and usually will not produce the necessary low hydraulic conductivity. Soils with plasticity indices greater than 30 to 40 percent are difficult to work with, as they form hard chunks when dry and sticky clods when wet, which make them difficult to work with in the field. Such soils also tend to have high shrink/swell potential and may not be suitable for this

Table 2-4. **Calculated Flow Rates for Soil Liners, Geomembrane Liners, and Composite Liners**

Type of Liner	Overall Quality of Liner	Assumed Values of Key Parameters	Rate of Flow (gal/acre/day)[a]
Compacted Soil	Poor	$k_5=1 \times 10^{-6}$ cm/s	1,200
Geomembrane	Poor	30 holes/acre; $a=0.1$ cm^2	10,000
Composite	Poor	$k_5=1 \times 10^{-6}$ cm/s 30 holes/acre; $a=0.1$ cm^2	100
Compacted Soil	Good	$k_5=1 \times 10^{-7}$ cm/s	120
Geomembrane	Good	1 hole/acre; $a=1$ cm^2	3,300
Composite	Good	$k_5=1 \times 10^{-7}$ cm/s 1 hole/acre; $a=1$ cm^2	0.8
Compacted Soil	Excellent	$k_5=1 \times 10^{-8}$ cm/s	12
Geomembrane	Excellent	1 hole/acre; $a=0.1$ cm^2	330
Composite	Excellent	$k_5=1 \times 10^{-8}$ cm/s 1 hole/acre; $a=0.1$ cm^2	0.1

[a]L = gal x 3.785

reason. Soils with plasticity indices between approximately 10 and 35 percent are generally ideal.

- *Percentage of Gravel* - The percentage of gravel (defined as material retained on the No. 4 sieve, which has openings of 4.76 mm) must not be excessive. A maximum amount of 10 percent gravel is suggested as a conservative figure. For many soils, however, larger amounts may not necessarily be deleterious if the gravel is uniformly distributed in the soil and does not interfere with compaction by footed rollers. For example, Shakoor and Cook found that the hydraulic conductivity of a compacted, clayey soil was insensitive to the amount of gravel present, as long as the gravel content did not exceed 50 percent (4). Gravel is only deleterious if the pores between gravel particles are not filled with clayey soil and the gravel forms a continuous pathway through the liner. The key problem to be avoided is segregation of gravel in pockets that contain little or no fine-grained soil.

- *Stones and Rocks* - No stones or rocks larger than 2.5 to 5 cm (1 to 2 in.) in diameter should be present in the liner material.

If the soil material does not contain enough clay or other fine-grained minerals to be capable of being compacted to the desired low hydraulic conductivity, commercially produced clay minerals, such as sodium bentonite, may be mixed with the soil. Figure 2-3 shows the relationship between the percentage of bentonite added to a soil and the hydraulic conductivity after compaction for a well-graded, silty soil that was carefully mixed in the laboratory. The percentage of bentonite is defined as the dry weight of bentonite divided by the dry weight of soil to which the bentonite is added (W_b/W_s). For well-graded soils containing a wide range of grain sizes, adding just a small amount of bentonite will usually lower the hydraulic conductivity of the soil to below 1 x 10^{-7}. For poorly graded soils, e.g., those with a uniform grain size, more bentonite is often needed.

Bentonite can be added to soil in two ways. One technique is to spread the soil to be amended over an area in a loose lift approximately 23 to 30 cm (9- to 12-in.) thick. Bentonite is then applied to the surface at a controlled rate and mixed into the soil using mechanical mixing equipment, such as a rototiller or road reclaimer (recycler). Multiple passes of the mixing equipment are usually recommended. The second procedure is to mix the ingredients in a pugmill, which is a large device used to mix bulk materials such as the ingredients that form Portland cement concrete. Bulk mixing in a pugmill usually provides more controlled mixing than combining ingredients in place in a loose lift of soil. However, mixing of bentonite into a loose lift of soil can be adequate if the mixing is done carefully with multiple passes of mechanical mixers and careful control over rates of application and depth of mixing. The reason why bulk mixing is usually recommended is that control over the mixing process is easier.

Water Content

The water content of the soil at the time it is compacted is an important variable controlling the engineering properties of soil liner materials. The lower half of Figure 2-4 shows a soil compaction curve. If soil samples are mixed at several water contents and then compacted with a consistent method and energy of compaction, the result is the relationship between dry unit weight and molding water content shown in the lower half of Figure 2-4. The molding water content at which the maximum dry unit weight is observed is termed the "optimum water content" and is indicated in Figure 2-4 with a dashed vertical line. Soils compacted at water contents less than optimum ("dry of optimum") tend to have a relatively high hydraulic conductivity whereas soils compacted at water contents greater than optimum ("wet of optimum") tend to have a low hydraulic conductivity. It is usually preferable to com

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ATTACHMENT 3

APPENDIX E
TABLE 3
MINIMUM LINER DESIGN AND PERFORMANCE STANDARDS

Liner Material*	Liner Function**	Field/Lab Liner Permeability (cm/sec)	Liner Thickness (minimum)	Liner Density # (test as noted)	Remarks***
Natural clays or inplace confining layers	Primary	Not acceptable for primary liner			Field verification of continuity of confining layer shall be evaluated through borings or backhoe pits. Also must have a minimum of 20% clay as classified by the USDA grainsize classification system.
	Secondary	$< 1 \times 10^{-7}$	4 + 0.5 ft.	NA	
	Cap	Not acceptable for Cap			
Hydraulic Asphalt Concrete	Primary	Not acceptable for primary liner			Minimum asphalt content shall be 6.5—9.0% by weight. All asphalt liners and joints shall be sealed with a seal coat of AC-20 or equivalent, applied in one or more applications for a total rate of at least 0.6 gallons/yd², and applied with at least a 1-foot wide overlap. Sections of asphalt shall be joined to adjacent sections by cutting a new edge on the existing section, coating the new edge with AC-20 or equivalent, butting the new section of asphalt against the coated edge, and sealing with AC-20 or equivalent.
	Secondary	$< 1 \times 10^{-7}$	2 inches	>96%	
	Cap	Not acceptable for Cap			
Soil Cement	Primary	$< 1 \times 10^{-7}$	12 inches	>97%	Minimum cement content shall be 10% by weight. Wet-dry and freeze-thaw cycle tests (ASTM D559 and ASTM D560) shall be performed to determine optimum cement content. The type of cement used shall be the type best suited to the type of soil to be used. A seal coat of AC-20 or equivalent shall be applied.
	Secondary	$< 1 \times 10^{-7}$	6 inches	>97%	
	Cap	$< 1 \times 10^{-7}$	12 inches	>97% (Standard Proctor method)	
Soil Asphalt	Primary	Not acceptable for primary liner			A seal coat of AC-20 or equivalent applied at a minimum total rate of 0.6 gal/yd² in two applications of 0.3 gal/yd² each. No cut back asphalt shall be used as a liner material. Sealer shall be applied with a minimum 1-foot overlap.
	Secondary	$< 1 \times 10^{-7}$	6 inches	>96% (Marshall method)	
	Cap	Not acceptable for Cap			

Liner Material*	Liner Function**	Field/Lab Liner Permeability (cm/sec)	Liner Thickness (minimum)	Liner Density # (test as noted)	Remarks***
Natural & Remolded Clay##	Secondary	$< 1.0 \times 10^{-7}$	3 feet	≥90%	1. Minimum of 30% fines by weight less than 0.074 mm particle size (# 200 sieve). 2. Plasticity index greater than or equal to 10. 3. No coarse fragments greater than 3/4 inch in diameter.
	Cap	$< 1.0 \times 10^{-7}$	2 feet	≥90% (Standard Proctor method)	
Sodium bentonite & Bentonite-like materials/soil mixtures##	Secondary	$< 1.0 \times 10^{-7}$	3 feet	≥90%	1. Minimum of 8% powdered sodium bentonite or manufacturer's recommendations, whichever is greater. 2. No coarse fragments greater than 3/4 inch in diameter. 3. No organic matter.
	Cap	$< 1.0 \times 10^{-7}$	2 feet	≥90% (Standard Proctor method)	
Geo-membranes	Primary	$< 1.0 \times 10^{-7}$	50 mil	N/A	
	Secondary	$< 1.0 \times 10^{-7}$	50 mil	N/A	
	Cap	$< 1.0 \times 10^{-7}$	50 mil	N/A	

* All liner materials and liner construction shall meet manufacturer's specification unless a more stringent specification is given in this table.
** Liner shall be compatible with waste it will contain.
*** Other tests relevant to the type of liner shall be performed if required by the Department.
\# Percentage is of maximum theoretical density when using Marshall method, and percentage of maximum density when using Standard Proctor method.
\## Not acceptable for use as (primary liner or) cap for landfills or surface impoundments used for disposal unless otherwise approved in writing by the Department.
N/A Not applicable

Authority

The provisions of this Appendix E amended under the act of July 28, 1988 (P. L. 556, No. 101) (53 P. S. §§ 4000.101—4000.1904); the act of October 18, 1988 (P. L. 756, No. 108) (35 P. S. §§ 6020.101—6020.1305); the act of June 22, 1937 (P. L. 1987, No. 394) (35 P. S. §§ 691.1—691.1001); the act of April 9, 1982 (P. L. 314, No. 89) (58 P. S. §§ 471—480); section 5 of the act of January 8, 1960 (P. L. 2119, No. 787) (35 P. S. § 4005); and section 1920-A of the act of April 9, 1929 (P. L. 177, No. 175) (71 P. S. § 510-20).

Source

The provisions of this Appendix E amended January 15, 1993, effective January 16, 1993, 23 Pa.B. 363; corrected January 22, 1993, effective January 16, 1993, 23 Pa.B. 462. Immediately preceding text appears at serial pages (145652) to (145653).

Cross References

This appendix cited in 25 Pa. Code § 264.222 (relating to design requirements—liner system); 25 Pa. Code § 264.257 (relating to special requirements for incompatible wastes); and 25 Pa. Code § 264.302 (relating to design requirements—liner system).

ATTACHMENT 4

INTERIM

USER'S GUIDE FOR HELP VERSION 2

FOR EXPERIENCED USERS

Introduction

This guide is intended for users who are familiar with running HELP Version 1. This guide describes the major changes to HELP Version 1 which have been incorporated into HELP Version 2. Complete details for running the model are not provided here.

Climatological Input

In addition to the default and manual methods of entering rainfall data, HELP Version 2 offers a synthetic method. The WGEN model, a synthetic weather generator developed by the Agriculture Research Service, has been incorporated into the HELP model. The synthetic weather generator produces daily values of precipitation, minimum and maximum temperature, and solar radiation. Version 2 uses the synthetic weather generator to produce daily values of mean temperature and solar radiation regardless of the method of rainfall input. Input of data for the other climatological parameters has also undergone some revisions.

Rainfall

The rainfall data entered by either of the three methods is stored in a data file named DATA4. In Version 1 the rainfall data is stored in a data file named TAPE4. The format of both data files is identical; the rainfall values are reported in inches with two decimal places. Old rainfall data files built as TAPE4 may be used in HELP Version 2 by renaming the files DATA4.

Synthetic Option. Due to the addition of the synthetic weather generator, HELP can generate daily rainfall for many cities throughout the country. The WGEN model uses a first-order Markov chain to generate the occurrence of wet or dry days. The probability of rain on a given day is conditioned on the wet or dry status of the previous day. For wet days (days with rainfall of 0.01 inch or more) a two parameter gamma distribution is used to determine the amount of rainfall. WGEN requires four parameters to generate rainfall: the probability of a wet day given that it was dry the previous day, the probability of a wet day given that it was wet on the previous day, a shape parameter and a scale parameter used in the gamma distribution. Each of these four parameters is constant for a given month but varies from month to month. The values of these parameters for each

of the 139 cities listed in Table 1 are stored in a data file named TAPE1. For PC users, a diskette containing these parameters is included with the program.° HELP Version 2 can use up to twenty years of daily precipitation values in its simulations, but the synthetic weather generator can produce as many years of data as you like within the limitation of memory space to store the generated values.

Default Option. HELP Version 2 reads five-year daily data sets of precipitation from data file TAPE3 instead of data file TAPE9. TAPE3 contains five-year precipitation data sets for each of the 102 cities listed in Table 2; these are the same values available in Version 1. Unlike TAPE9 of Version 1, TAPE3 does not contain mean monthly temperatures, mean monthly insolation values, and leaf area indices for fractional parts of the growing season because of the addition of the synthetic weather generator and a vegetative growth model containing or generating these values.

Manual Option. In the manual or user specified rainfall input option, a user may enter a new set of precipitation data; add, delete, or replace years of data in an existing set of precipitation data; or edit daily values from an existing precipitation data set entered by any option. If the user modifies rainfall in any way, the program will compute new daily temperatures and solar radiation values since rainfall influences these parameters. The user may enter or modify rainfall for any of the 184 cities listed in Table 3. The synthetic weather generator has routines to correct the rainfall and temperature values from these 184 cities to your actual site. The program can store up to twenty years of daily rainfall.

Other Climatological Parameters

HELP Version 2 synthetically generates temperature and solar radiation, and handles input of maximum leaf area index and evaporative zone depth identically in the synthetic, manual, and default options. Users can edit the maximum leaf area index and evaporative zone depth in the manual rainfall option. Winter cover factor and vegetation type are no longer entered. These data are stored in different data files and different formats than used in Version 1.

Temperature and Solar Radiation. The WGEN synthetic weather generator incorporated into HELP Version 2 computes daily values of temperature and solar radiation. Richardson (1981) describes the procedure for generating daily maximum and minimum temperature values and mean solar radiation values. The WGEN model requires several statistical coefficients describing the distribution of maximum and minimum temperatures and mean solar radiation. Values of these coefficients for each of the 184 cities listed in Table 3 are stored in a data file named TAPE2. The WGEN model as applied in HELP Version 2 also requires the normal mean monthly temperatures to provide better predicted temperature values. These temperatures for the 184 cities are also stored in TAPE2. For PC users, the data file is included on the diskette containing the rainfall generation parameters. The generated daily temperatures and solar radiation values are a function of the rainfall, and therefore the rainfall data must be entered and corrected as desired before the final temperature and solar radiation values can be generated. Therefore, it is important to go through the manual climatological data input routine before running the simulation if the

TABLE 1. LISTING OF DEFAULT CITIES CONTAINING SYNTHETIC RAINFALL DATA

- ALABAMA
  - BIRMINGHAM
  - MOBILE
  - MONTGOMERY
- ARIZONA
  - FLAGSTAFF
  - PHOENIX
  - YUMA
- ARKANSAS
  - FORT SMITH
  - LITTLE ROCK
- CALIFORNIA
  - BAKERSFIELD
  - BLUE CANYON
  - EUREKA
  - FRESNO
  - MT. SHASTA
  - SAN DIEGO
  - SAN FRANCISCO
- COLORADO
  - COLORADO SPGS
  - DENVER
  - GRAND JUNCTION
  - PUEBLO
- CONNECTICUT
  - WINDSOR LOCKS
- DELAWARE
  - WILMINGTON
- DIST. OF COLUMBIA
  - WASHINGTON
- FLORIDA
  - JACKSONVILLE
  - MIAMI
  - TALLAHASSEE
  - TAMPA
- GEORGIA
  - ATLANTA
  - AUGUSTA
  - MACON
  - SAVANNAH
- HAWAII
  - HONOLULU
- IDAHO
  - BOISE
  - POCATELLO
- ILLINOIS
  - CHICAGO
- INDIANA
  - EVANSVILLE
  - FORT WAYNE
  - INDIANAPOLIS
- IOWA
  - DES MOINES
  - DUBUQUE
- KANSAS
  - DODGE CITY
  - TOPEKA
  - WICHITA
- KENTUCKY
  - COVINGTON
  - LEXINGTON
  - LOUISVILLE
- LOUISIANA
  - BATON ROUGE
  - NEW ORLEANS
  - SHREVEPORT
- MAINE
  - CARIBOU
  - PORTLAND
- MARYLAND
  - BALTIMORE
- MASSACHUSETTS
  - BOSTON
  - NANTUCKET
- MICHIGAN
  - DETROIT
  - GRAND RAPIDS
- MINNESOTA
  - DULUTH
  - MINNEAPOLIS
- MISSISSIPPI
  - JACKSON
  - MERIDIAN
- MISSOURI
  - COLUMBIA
  - KANSAS CITY
  - ST. LOUIS
- MONTANA
  - BILLINGS
  - GREAT FALLS
  - HAVRE
  - HELENA
  - KALISPELL
  - MILES CITY
- NEBRASKA
  - GRAND ISLAND
  - NORTH PLATTE
  - SCOTTSBLUFF
- NEVADA
  - ELKO
  - LAS VEGAS
  - RENO
  - WINNEMUCCA
- NEW HAMPSHIRE
  - CONCORD
  - MT. WASHINGTON
- NEW JERSEY
  - NEWARK
- NEW MEXICO
  - ALBUQUERQUE
  - ROSWELL
- NEW YORK
  - ALBANY
  - BUFFALO
  - NEW YORK
  - SYRACUSE
- NORTH CAROLINA
  - ASHEVILLE
  - CHARLOTTE
  - GREENSBORO
  - RALEIGH
- NORTH DAKOTA
  - BISMARCK
  - WILLISTON
- OHIO
  - CLEVELAND
  - COLUMBUS
  - TOLEDO
- OKLAHOMA
  - OKLAHOMA CITY
  - TULSA
- OREGON
  - BURNS
  - MEACHEM
  - MEDFORD
  - PENDLETON
  - PORTLAND
  - SALEM
  - SEXT. SUMMIT
- PENNSYLVANIA
  - PHILADELPHIA
  - PITTSBURGH
- RHODE ISLAND
  - PROVIDENCE
- SOUTH CAROLINA
  - CHARLESTON
  - COLUMBIA
- SOUTH DAKOTA
  - HURON
  - RAPID CITY
- TENNESSEE
  - CHATTANOOGA
  - KNOXVILLE
  - MEMPHIS
  - NASHVILLE
- TEXAS
  - ABILENE
  - AMARILLO
  - AUSTIN
  - BROWNSVILLE
  - CORPUS CHRISTI
  - DALLAS
  - EL PASO
  - GALVESTON
  - HOUSTON
  - SAN ANTONIO
  - TEMPLE
  - WACO
- UTAH
  - MILFORD
  - SALT LAKE
- VIRGINIA
  - NORFOLK
  - RICHMOND
- WASHINGTON
  - OLYMPIA
  - SPOKANE
  - STAMPEDE PASS
  - WALLA WALLA
  - YAKIMA
- WEST VIRGINIA
  - CHARLESTON
- WISCONSIN
  - GREEN BAY
  - LACROSSE
  - MADISON
  - MILWAUKEE
- WYOMING
  - CHEYENNE
- PUERTO RICO
  - SAN JUAN

TABLE 2. LISTING OF DEFAULT CITIES CONTAINING DEFAULT RAINFALL DATA

- ALASKA
  - ANNETTE
  - BETHEL
  - FAIRBANKS
- ARIZONA
  - FLAGSTAFF
  - PHOENIX
  - TUCSON
- ARKANSAS
  - LITTLE ROCK
- CALIFORNIA
  - FRESNO
  - LOS ANGELES
  - SACRAMENTO
  - SAN DIEGO
  - SANTA MARIA
- COLORADO
  - DENVER
  - GRAND JUNCTION
- CONNECTICUT
  - BRIDGEPORT
  - HARTFORD
  - NEW HAVEN
- FLORIDA
  - JACKSONVILLE
  - MIAMI
  - ORLANDO
  - TALLAHASSEE
  - TAMPA
  - W. PALM BEACH
- GEORGIA
  - ATLANTA
  - WATKINSVILLE
- HAWAII
  - HONOLULU
- IDAHO
  - BOISE
  - POCATELLO
- ILLINOIS
  - CHICAGO
  - E. ST. LOUIS
- INDIANA
  - INDIANAPOLIS
- IOWA
  - DES MOINES
- KANSAS
  - DODGE CITY
  - TOPEKA
- KENTUCKY
  - LEXINGTON
- LOUISIANA
  - LAKE CHARLES
  - NEW ORLEANS
  - SHREVEPORT
- MAINE
  - AUGUSTA
  - BANGOR
  - CARIBOU
  - PORTLAND
- MASSACHUSETTS
  - BOSTON
  - PLAINFIELD
  - WORCESTER
- MICHIGAN
  - E. LANSING
  - SAULT STE. MARIE
- MINNESOTA
  - ST. CLOUD
- MISSOURI
  - COLUMBIA
- MONTANA
  - GLASGOW
  - GREAT FALLS
- NEBRASKA
  - GRAND ISLAND
  - NORTH OMAHA
- NEVADA
  - ELY
  - LAS VEGAS
- NEW HAMPSHIRE
  - CONCORD
  - NASHUA
- NEW JERSEY
  - EDISON
  - SEABROOK
- NEW MEXICO
  - ALBUQUERQUE
- NEW YORK
  - ALBANY
  - CENTRAL PARK
  - ITHACA
  - NEW YORK CITY
  - SYRACUSE
- NORTH CAROLINA
  - GREENSBORO
- NORTH DAKOTA
  - BISMARCK
- OHIO
  - CINCINNATI
  - CLEVELAND
  - COLUMBUS
  - PUT-IN-BAY
- OKLAHOMA
  - OKLAHOMA CITY
  - TULSA
- OREGON
  - ASTORIA
  - MEDFORD
  - PORTLAND
- PENNSYLVANIA
  - PHILADELPHIA
  - PITTSBURGH
- RHODE ISLAND
  - PROVIDENCE
- SOUTH CAROLINA
  - CHARLESTON
- SOUTH DAKOTA
  - RAPID CITY
- TENNESSEE
  - KNOXVILLE
  - NASHVILLE
- TEXAS
  - BROWNSVILLE
  - DALLAS
  - EL PASO
  - MIDLAND
  - SAN ANTONIO
- UTAH
  - CEDAR CITY
  - SALT LAKE CITY
- VERMONT
  - BURLINGTON
  - MONTPELIER
  - RUTLAND
- VIRGINIA
  - LYNCHBURG
  - NORFOLK
- WASHINGTON
  - PULLMAN
  - SEATTLE
  - YAKIMA
- WISCONSIN
  - MADISON
- WYOMING
  - CHEYENNE
  - LANDER
- PUERTO RICO
  - SAN JUAN

TABLE 3. LISTING OF DEFAULT CITIES CONTAINING SYNTHETIC TEMPERATURE AND SOLAR RADIATION DATA

- ALABAMA
  - BIRMINGHAM
  - MOBILE
  - MONTGOMERY
- ALASKA
  - ANNETTE
  - BETHEL
  - FAIRBANKS
- ARIZONA
  - FLAGSTAFF
  - PHOENIX
  - TUCSON
  - YUMA
- ARKANSAS
  - FORT SMITH
  - LITTLE ROCK
- CALIFORNIA
  - BAKERSFIELD
  - BLUE CANYON
  - EUREKA
  - LOS ANGELES
  - FRESNO
  - MT. SHASTA
  - SACRAMENTO
  - SAN DIEGO
  - SAN FRANCISCO
  - SANTA MARIA
- COLORADO
  - COLORADO SPGS
  - DENVER
  - GRAND JUNCTION
  - PUEBLO
- CONNECTICUT
  - BRIDGEPORT
  - HARTFORD
  - NEW HAVEN
  - WINDSOR LOCKS
- DELAWARE
  - WILMINGTON
- DIST. OF COLUMBIA
  - WASHINGTON
- FLORIDA
  - JACKSONVILLE
  - MIAMI
  - ORLANDO
  - TALLAHASSEE
  - TAMPA
  - W. PALM BEACH
- ILLINOIS
  - CHICAGO
  - E. ST. LOUIS
- INDIANA
  - EVANSVILLE
  - FORT WAYNE
  - INDIANAPOLIS
- IOWA
  - DES MOINES
  - DUBUQUE
- KANSAS
  - DODGE CITY
  - TOPEKA
  - WICHITA
- KENTUCKY
  - COVINGTON
  - LEXINGTON
  - LOUISVILLE
- LOUISIANA
  - BATON ROUGE
  - LAKE CHARLES
  - NEW ORLEANS
  - SHREVEPORT
- MAINE
  - AUGUSTA
  - BANGOR
  - CARIBOU
  - PORTLAND
- MARYLAND
  - BALTIMORE
- MASSACHUSETTS
  - BOSTON
  - NANTUCKET
  - PLAINFIELD
  - WORCHESTER
- MICHIGAN
  - DETROIT
  - E. LANSING
  - GRAND RAPIDS
  - SAUL STE. MARIE
- MINNESOTA
  - DULUTH
  - MINNEAPOLIS
  - ST. CLOUD
- MISSISSIPPI
  - JACKSON
  - MERIDIAN
- NEBRASKA
  - GRAND ISLAND
  - NORTH PLATTE
  - OMAHA
  - SCOTTSBLUFF
- NEVADA
  - ELKO
  - ELY
  - LAS VEGAS
  - RENO
  - WINNEMUCCA
- NEW HAMPSHIRE
  - CONCORD
  - MT. WASHINGTON
  - NASHUA
- NEW JERSEY
  - EDISON
  - NEWARK
  - SEABROOK
- NEW MEXICO
  - ALBUQUERQUE
  - ROSWELL
- NEW YORK
  - ALBANY
  - BUFFALO
  - CENTRAL PARK
  - ITHACA
  - NEW YORK CITY
  - SCHENECTADY
  - SYRACUSE
- NORTH CAROLINA
  - ASHEVILLE
  - CHARLOTTE
  - GREENSBORO
  - RALEIGH
- NORTH DAKOTA
  - BISMARCK
  - WILLISTON
- OHIO
  - CINCINNATI
  - CLEVELAND
  - COLUMBUS
  - PUT-IN-BAY
  - TOLEDO
- OKLAHOMA
  - OKLAHOMA CITY
  - TULSA
- RHODE ISLAND
  - PROVIDENCE
- SOUTH CAROLINA
  - CHARLESTON
  - COLUMBIA
- SOUTH DAKOTA
  - HURON
  - RAPID CITY
- TENNESSEE
  - CHATTANOOGA
  - KNOXVILLE
  - MEMPHIS
  - NASHVILLE
- TEXAS
  - ABILENE
  - AMARILLO
  - AUSTIN
  - BROWNSVILLE
  - CORPUS CHRISTI
  - DALLAS
  - EL PASO
  - GALVESTON
  - HOUSTON
  - MIDLAND
  - SAN ANTONIO
  - TEMPLE
  - WACO
- UTAH
  - CEDAR CITY
  - MILFORD
  - SALT LAKE CITY
- VERMONT
  - BURLINGTON
  - MONTPELIER
  - RUTLAND
- VIRGINIA
  - LYNCHBURG
  - NORFOLK
  - RICHMOND
- WASHINGTON
  - OLYMPIA
  - PULLMAN
  - SEATTLE
  - SPOKANE
  - STAMPEDE PASS
  - WALLA WALLA
  - YAKIMA

(Continued)

TABLE 3. (Concluded)

GEORGIA	MISSOURI	OREGON	WEST VIRGINIA
ATLANTA	COLUMBIA	ASTORIA	CHARLESTON
AUGUSTA	KANSAS CITY	BURNS	WISCONSIN
MACON	ST. LOUIS	MEACHAM	GREEN BAY
SAVANNAH	MONTANA	MEDFORD	LACROSSE
WATKINSVILLE	BILLINGS	PENDLETON	MADISON
HAWAII	GLASGOW	PORTLAND	MILWAUKEE
HONOLULU	GREAT FALLS	SALEM	WYOMING
IDAHO	HAVRE	SEXT. SUMMIT	CHEYENNE
BOISE	HELENA	PENNSYLVANIA	LANDER
POCATELLO	KALISPELL	PHILADELPHIA	PUERTO RICO
	MILES CITY	PITTSBURGH	SAN JUAN

rainfall data was edited or created outside of the HELP Version 2 program. The statistical coefficients and normal mean monthly temperatures for the selected city are stored in a data file named DATA11. The daily temperature and daily solar radiation values are stored respectively in data files named DATA7 and DATA13.

Leaf Area Indices. HELP Version 2 requires a maximum leaf area index for the location to compute daily leaf area indices by a vegetative growth model incorporated in Version 2. The vegetative growth model used was extracted from the SWRRB (A Simulator for Water Resources in Rural Basins) model developed by the Agriculture Research Service. The daily leaf area indices during the growing season are computed during execution, considering temperature and water stress besides the maximum leaf area index and the beginning and ending dates of the growing season (planting and harvesting dates). These values are also stored in data file TAPE2 with the temperature and solar radiation parameters and coefficients. The values of maximum leaf area index and growing season dates for the selected city are stored in data file DATA11. The same value of maximum leaf area index is used for each year of the simulation. The program prompts for the maximum leaf area index by displaying typical values for different levels of vegetative cover likely to be achieved with the level of management of the landfill (such as, fertilization, soil quality, watering, seeding, etc.). For example,

```
ENTER THE MAXIMUM LEAF AREA INDEX.

TYPICAL VALUES ARE:

                 0.0 FOR BARE GROUND
                 1.0 FOR POOR GRASS
                 2.0 FOR FAIR GRASS
                 3.3 FOR GOOD GRASS
                 5.0 FOR EXCELLENT GRASS
```

These values are somewhat higher than recommended in Version 1.

Evaporative Zone Depth. HELP Version 2 prompts the user to enter an evaporative zone depth by displaying typical values for the location based on the vegetative cover type. For example,

```
ENTER THE EVAPORATIVE ZONE DEPTH IN INCHES.

 TYPICAL VALUES FOR PHILADELPHIA      PENNSYLVANIA     ARE:
            9 IN. FOR BARE GROUND
           21 IN. FOR FAIR GRASS
           38 IN. FOR EXCELLENT GRASS
```

The typical evaporative zone depths shown are stored in data file TAPE2 for each of the 184 cities listed in Table 3. The selected evaporative zone depth is stored in data file DATA11.

Soil and Design Data Input

Several changes were also included in the soil and design data input for HELP Version 2. The principal changes are presented below. The more significant changes are a revised set of default soil characteristics, the option of specifying the initial moisture content of all layers except the liners, new classification of layer types, an increase in the number of layers permitted, and the elimination of the input of an evaporation coefficient. The soil and design data are stored in a data file named DATA10; its format is different from the data file used in Version 1.

Initial Soil Water

HELP Version 2 allows the user the option of entering the initial soil water content of all layers except liners or having the program calculate the initial soil water contents. If the program initializes the soil water, the program assigns the same soil moisture values used in Version 1 and then runs one year of simulation using the first year of climatological data to initialize the soil water. The program then starts the simulation using the first year of climatological data again to determine water balance components. The model does not repeat the first year of calculations if the user specifies the initial soil water. The initialization option is provided by the following question.

DO YOU WANT THE PROGRAM TO INITIALIZE THE SOIL WATER CONTENT FOR EACH LAYER? IF YOU ANSWER NO, YOU WILL BE ASKED TO ENTER THE SOIL WATER CONTENT FOR EACH LAYER. ENTER YES OR NO.

Number of Layers

HELP Version 2 allows a total of 12 layers and 4 barrier soil liners instead of 9 and 3, respectively, in HELP Version 1. The program prints this message concerning layers.

THREE TYPES OF LAYERS MAY BE USED IN THE DESIGN:
VERTICAL PERCOLATION, LATERAL DRAINAGE, AND BARRIER SOIL LINER.

A LAYER OF MODERATE TO HIGH PERMEABILITY MATERIAL WITHOUT DRAINAGE COLLECTION SYSTEMS IS CLASSIFIED AS A VERTICAL PERCOLATION LAYER.

A LAYER PERMITTING LATERAL DRAINAGE TO COLLECTION SYSTEMS OR PERIMETER DRAINS IS CLASSIFIED AS A LATERAL DRAINAGE LAYER. VERTICAL DRAINAGE AND LATERAL DRAINAGE BOTH OCCUR IN A LATERAL DRAINAGE LAYER.

A LAYER OF MATERIAL DESIGNED TO INHIBIT PERCOLATION IS CLASSIFIED AS A BARRIER SOIL LINER. IN ADDITION, A LAYER OR A PART OF A LAYER OF MATERIAL COVERED BY A FLEXIBLE MEMBRANE LINER IS CLASSIFIED AS A BARRIER SOIL LINER WITH A FLEXIBLE MEMBRANE LINER.

```
**** RULES ****
1. THE TOP LAYER CANNOT BE A BARRIER SOIL LINER.
2. A BARRIER SOIL LINER MAY NOT BE ADJACENT TO ANOTHER SOIL LINER.
3. A VERTICAL PERCOLATION LAYER MAY NOT BE PLACED DIRECTLY BELOW
   A LATERAL DRAINAGE LAYER.

ENTER THE NUMBER OF LAYERS IN YOUR DESIGN.
YOU MAY USE UP TO 12 LAYERS AND UP TO 4 BARRIER SOIL LINERS.
```

Layer Types

HELP Version 2 uses four layer types, each named for the manner that it functions as described above. The layer type called WASTE in Version 1 is not used in Version 2. The layer types are numbered as described in the program as follows:

```
ENTER THE LAYER TYPE FOR LAYER  1.

ENTER 1 FOR A VERTICAL PERCOLATION LAYER,
      2 FOR A LATERAL DRAINAGE LAYER,
      3 FOR A BARRIER SOIL LINER, OR
      4 FOR A BARRIER SOIL LINER WITH
        A FLEXIBLE MEMBRANE LINER.
```

Default Soil Types

HELP Version 2 uses a revised set of default soil characteristics based on a more extensive recently published description of soil characteristics that also provided information on parameters required for the new unsaturated hydraulic conductivity relationship used in this version. Table 4 lists the default soil types and characteristics used in HELP Version 2. The default runoff curve number relationship for calculating the curve number as a function of the soil type and vegetation level has also been updated.

Execution

Changes in Modeling Routines

Many changes have been made to the execution of the HELP model in Version 2; some have already been mentioned. The program now uses synthetically derived daily temperatures and solar radiation values in the calculation of snowmelt and evapotranspiration instead of interpolated temperatures based on mean monthly temperatures. The snowmelt routine is virtually identical to the previous routine except that the base temperature for snowmelt to start to occur has been lowered to account for the difference between daily maximum temperature and daily average temperature. Use of synthetically derived temperatures greatly improves snow accumulation, runoff, and infiltration during the winter months for colder regions. Daily solar radiation values improves daily predictions of evapotranspiration.

TABLE 4. DEFAULT UNVEGETATED, UNCOMPACTED SOIL CHARACTERISTICS

SOIL TEXTURE HELP	USDA	USCS	POROSITY (VOL/VOL)	FIELD CAPACITY (VOL/VOL)	WILTING POINT (VOL/VOL)	SAT. HYD. CONDUCTIVITY (CM/SEC)
1	CoS	GS	0.417	0.045	0.018	1.0E-02
2	S	SW	0.437	0.062	0.024	5.8E-03
3	FS	SM	0.457	0.083	0.033	3.1E-03
4	LS	SM	0.437	0.105	0.047	1.7E-03
5	LFS	SM	0.457	0.131	0.058	1.0E-03
6	SL	SM	0.453	0.190	0.085	7.2E-04
7	FSL	SM	0.473	0.222	0.104	5.2E-04
8	L	ML	0.463	0.232	0.116	3.7E-04
9	SiL	ML	0.501	0.284	0.135	1.9E-04
10	SCL	SC	0.398	0.244	0.136	1.2E-04
11	CL	CL	0.464	0.310	0.187	6.4E-05
12	SiCL	CL	0.471	0.342	0.210	4.2E-05
13	SC	CH	0.430	0.321	0.221	3.3E-05
14	SiC	CH	0.479	0.371	0.251	2.5E-05
15	C	CH	0.475	0.378	0.265	1.7E-05
16	Liner Soil		0.430	0.366	0.280	1.0E-07
17	Liner Soil		0.400	0.356	0.290	1.0E-08
18	Mun. Waste		0.520	0.294	0.140	2.0E-04
19	USER SPECIFIED SOIL CHARACTERISTICS					
20	USER SPECIFIED SOIL CHARACTERISTICS					

Evapotranspiration modeling has also been modified in several other small ways while still using the same methods as before. The surface evaporation routine has been changed to compute the evaporation as a function of plant interception and accumulated snow. The albedo is now also corrected for snow accumulation. Plant transpiration and soil evaporation are functions of the quantity of live and decaying vegetation. Version 1 used typical leaf area indices and winter cover factors to describe the vegetation while Version 2 uses a vegetative growth and decay model to compute plant biomass and leaf area indices as a function of the specified vegetative condition, solar radiation, temperature and moisture.

Drainage calculations in Version 2 have been changed in several ways. Unsaturated hydraulic conductivity is now modeled as a function of soil moisture by a form of the Brooks-Corey equation which relates unsaturated hydraulic conductivity to a dimensionless soil moisture raised to a power. The lateral drainage equation was changed to permit use of drainage lengths up to 2000 feet and slopes up to 30 percent, while using the same theory as in Version 1. The vertical drainage routine was also modified to look ahead at the hydraulic conductivity of the layer below to determine whether it was able to accept the drainage; therefore, free drainage is no longer required for vertical percolation layers. This permits the use of layers of lower hydraulic conductivity, other than just barrier soil liners, below a vertical percolation layer or a lateral drainage layer.

Output

In the summary output, HELP Version 2 gives average monthly and annual standard deviations in addition to the monthly and annual means. Monthly and annual totals are printed identically to Version 1 except that their labels have been clarified to state which layers are discharging the lateral drainage and vertical percolation. The monthly output also lists mean monthly heads and monthly standard deviations of daily heads. Daily output, when there are two or less soil subprofiles (barrier soil liners), is identical in form to Version 1. When three or four subprofiles are used in the landfill design, the model allows the user to select up to six variables of either head on any of the barrier soil liners, lateral drainage from any of the lateral drainage layers directly above barrier soil liners, or vertical percolation through any of the barrier soil liners.

Computing Time Requirements

The computing time required to run a year of simulation with Version 2 is about 2 to 3 times as large as with Version 1. The increase in time requirements resulted primarily from three improvements in the HELP model: use of an iterative solution to solve the highly nonlinear relationship between soil moisture and unsaturated hydraulic conductivity, use of an iterative solution to solve the new nonlinear lateral drainage equation that greatly extends the applicability of the equation, and inclusion of a vegetative growth model to compute both decaying plant density and actively transpiring plant density as a function of temperature and soil temperature. A typical cover design with a lateral drainage layer takes about 6 minutes per year of simulation using a XT-type personal computer and about 2 minutes

per year using a AT-type computer. A complete landfill with a cover and a double liner requires about 10 minutes and 4 minutes per year of simulation respectively using XT and AT computers with math coprocessors.

Data Files

HELP Version 2 uses nine data files. Data files which are permanent and do not change during each run are identified with the prefix TAPE. Data files which are created by the HELP model during data input and used during execution are identified with the prefix DATA. These files contain the climatological, soil and design parameters for a particular simulation. The device number on which the program opens each data file, the file name, and contents of each file are given in Table 5.

TABLE 5. Data files used in HELP Version 2.

Device No.	Data File Name	Contents
1	TAPE1	Alpha and Beta coefficients for generating rainfall for 139 cities.
2	TAPE2	Temperature and radiation coefficients, rainfall probabilities, maximum leaf area index, planting and harvesting dates for 184 cities.
3	TAPE3	Five-year daily precipitation data sets for 102 cities.
4	DATA4	Daily precipitation in inches for user specified city.
7	DATA7	Average daily values of temperature in degrees F. for user specified city.
8	User Specified	Output from HELP model simulation.
10	DATA10	Soil design data.
11	DATA11	Coefficients from TAPE2 for user specified city.
13	DATA13	Daily values of solar radiation in langleys for user specified city.

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Schroeder, P. R., and R. L. Peyton. Verification of the Lateral Drainage Component of the HELP Model using Physical Models. EPA 600/2-87-049, U.S. Environmental Protection Agency, Cincinnati, OH, 1987. pp. 117.

USDA, Soil Conservation Service. National Engineering Handbook, Section 4, Hydrology. U.S. Government Printing Office, Washington, D.C., 1972.

TABLE 4. DEFAULT SOIL CHARACTERISTICS

Soil Texture Class			Total Poros.	Resid. Sat.	Bubbl. Press. (cm)	Pore-Size Dist. Index	Field Cap.	Wilt. Pt.	Sat. Hyd. Cond.		Min. Inf. Rate in/hr	Evap. Coef. $mm/day^{0.5}$
HELP	USDA	USCS							cm/s	in/hr		
1	CoS	GS	0.417	0.015	6.53	0.651	0.045	0.018	1.0E-02	14.173	0.500	3.3
2	S	SW	0.437	0.020	7.26	0.592	0.062	0.024	5.8E-03	8.220	0.400	3.3
3	FS	SM	0.457	0.025	7.99	0.533	0.083	0.033	3.1E-03	4.394	0.390	3.3
4	LS	SM	0.437	0.035	8.69	0.474	0.105	0.047	1.7E-03	2.409	0.380	3.3
5	LFS	SM	0.457	0.040	9.56	0.425	0.131	0.058	1.0E-03	1.417	0.340	3.3
6	SL	SM	0.453	0.041	14.66	0.322	0.190	0.085	7.2E-04	1.020	0.300	5.1
7	FSL	SM	0.473	0.046	16.13	0.290	0.222	0.104	5.2E-04	0.737	0.250	5.1
8	L	ML	0.463	0.027	11.15	0.220	0.232	0.116	3.7E-04	0.524	0.200	3.9
9	SiL	ML	0.501	0.015	20.76	0.211	0.284	0.135	1.9E-04	0.269	0.170	5.1
10	SCL	SC	0.398	0.068	28.08	0.250	0.244	0.136	1.2E-04	0.170	0.110	5.1
11	CL	CL	0.464	0.075	25.89	0.194	0.310	0.187	6.4E-05	0.091	0.090	5.1
12	SiCL	CL	0.471	0.040	32.56	0.151	0.342	0.210	4.2E-05	0.060	0.070	5.1
13	SC	CH	0.430	0.109	29.17	0.168	0.321	0.221	3.3E-05	0.047	0.060	4.5
14	SiC	CH	0.479	0.056	34.19	0.127	0.371	0.251	2.5E-05	0.035	0.020	5.1
15	C	CH	0.475	0.090	37.30	0.131	0.378	0.265	1.7E-05	0.024	0.010	4.6
16	Barrier		0.430	0.120	45.00	0.113	0.366	0.280	1.0E-07	0.000	0.002	3.3
17	Barrier		0.400	0.140	50.00	0.096	0.356	0.290	1.0E-08	0.000	0.001	3.3
18	Mun. Waste		0.520	0.015	20.76	0.211	0.294	0.140	2.0E-04	0.283	0.230	5.1

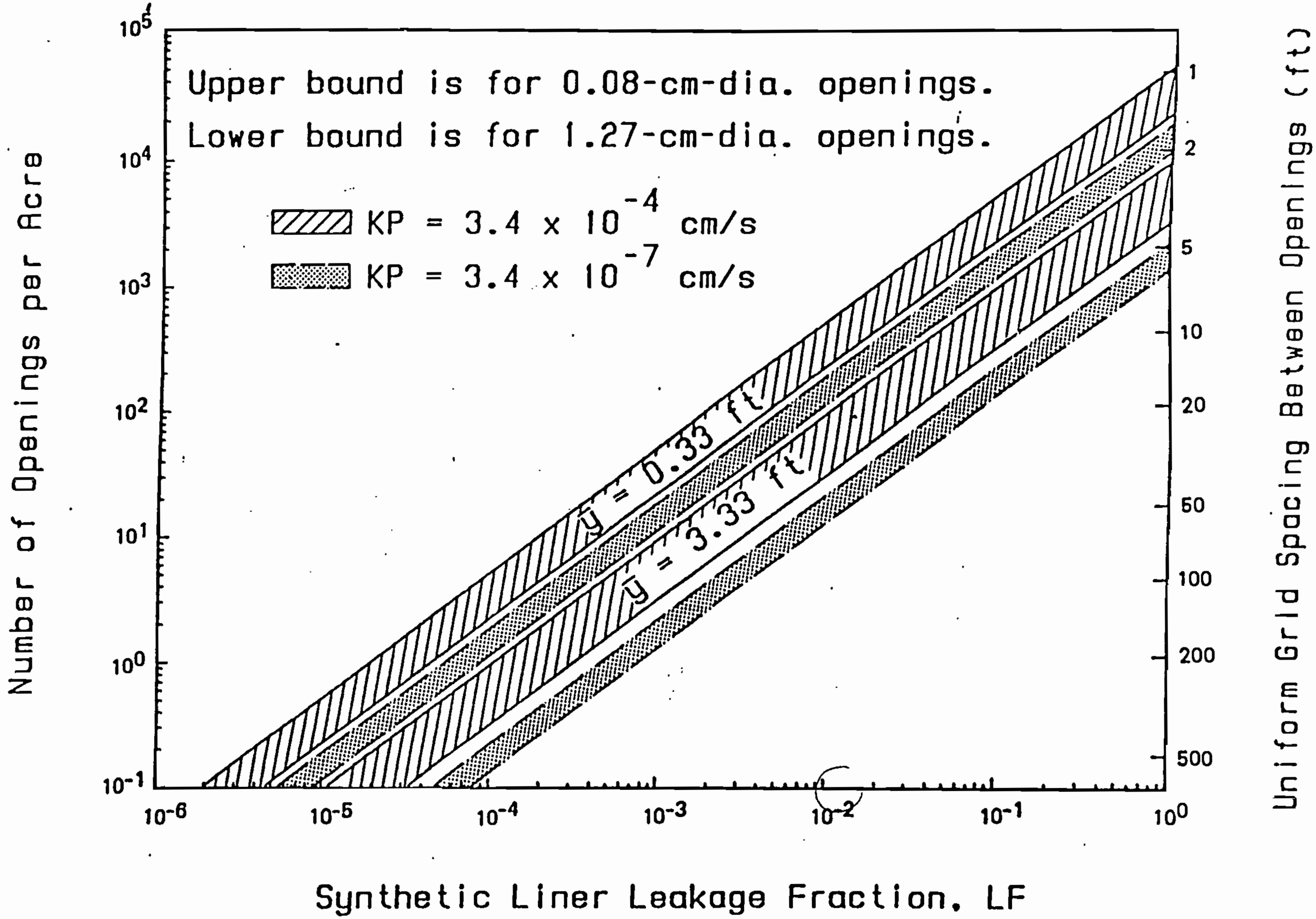

Figure 5. Synthetic liner leakage faction as a function of number of openings per acre and uniform grid spacing between openings.

ATTACHMENT 5

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NGK METALS CORPORATION-READING, PA
POND 1 EXISTING CONDITIONS
MAY 10, 1994

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                            BARE GROUND

                              LAYER  1
                              --------

                   VERTICAL PERCOLATION LAYER
  THICKNESS                            =     96.00 INCHES
  POROSITY                             =      0.4170 VOL/VOL
  FIELD CAPACITY                       =      0.0454 VOL/VOL
  WILTING POINT                        =      0.0200 VOL/VOL
  INITIAL SOIL WATER CONTENT           =      0.0454 VOL/VOL
  SATURATED HYDRAULIC CONDUCTIVITY     =      0.009999999776 CM/SEC


                      GENERAL SIMULATION DATA
                      -----------------------

  SCS RUNOFF CURVE NUMBER              =      90.00
  TOTAL AREA OF COVER                  =   28315. SQ FT
  EVAPORATIVE ZONE DEPTH               =       9.00 INCHES
  UPPER LIMIT VEG. STORAGE             =       3.7530 INCHES
  INITIAL VEG. STORAGE                 =       0.3764 INCHES
  INITIAL SNOW WATER CONTENT           =       0.0000 INCHES
  INITIAL TOTAL WATER STORAGE IN
    SOIL AND WASTE LAYERS              =       4.3584 INCHES

             SOIL WATER CONTENT INITIALIZED BY PROGRAM.


                        CLIMATOLOGICAL DATA
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  DEFAULT RAINFALL WITH SYNTHETIC DAILY TEMPERATURES AND
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SOLAR RADIATION FOR PHILADELPHIA PENNSYLVANIA

MAXIMUM LEAF AREA INDEX = 0.00
START OF GROWING SEASON (JULIAN DATE) = 115
END OF GROWING SEASON (JULIAN DATE) = 296

NORMAL MEAN MONTHLY TEMPERATURES, DEGREES FAHRENHEIT

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
31.20	33.10	41.80	52.90	62.80	71.60
76.50	75.30	68.20	56.50	45.80	35.50

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 74 THROUGH 78

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	4.59	1.88	4.09	3.03	3.85	4.50
	3.67	4.46	4.17	2.76	2.68	3.99
STD. DEVIATIONS	2.53	0.66	1.00	1.51	2.03	2.17
	1.95	2.49	2.07	1.21	2.63	1.78
RUNOFF						
TOTALS	0.739	0.211	0.657	0.356	0.479	0.491
	0.765	0.637	0.481	0.269	0.579	0.600
STD. DEVIATIONS	0.688	0.189	0.224	0.415	0.409	0.388
	0.724	0.414	0.681	0.121	0.899	0.424
EVAPOTRANSPIRATION						
TOTALS	0.995	1.169	1.949	1.640	2.465	2.651
	1.969	2.502	1.924	1.542	0.855	0.967
STD. DEVIATIONS	0.258	0.527	0.440	0.253	0.903	0.904
	0.916	1.381	0.560	0.745	0.367	0.311
PERCOLATION FROM LAYER 1						
TOTALS	2.1648	1.6930	1.1369	1.3753	1.1621	1.1783
	1.2359	1.1009	1.2681	1.3711	1.1643	1.7139
STD. DEVIATIONS	1.4219	0.9842	0.3784	0.4768	0.2889	0.6525
	0.7871	0.4305	0.4668	0.8831	0.7145	1.1726

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 74 THROUGH 78

	(INCHES)		(CU. FT.)	PERCENT
PRECIPITATION	43.67	(7.930)	103043.	100.00
RUNOFF	6.264	(2.242)	14781.	14.34
EVAPOTRANSPIRATION	20.628	(1.455)	48674.	47.24
PERCOLATION FROM LAYER 1	16.5647	(4.3852)	39086.	37.93
CHANGE IN WATER STORAGE	0.213	(1.604)	502.	0.49

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PEAK DAILY VALUES FOR YEARS 74 THROUGH 78

	(INCHES)	(CU. FT.)
PRECIPITATION	3.99	9414.7
RUNOFF	1.989	4693.4
PERCOLATION FROM LAYER 1	0.4371	1031.4
SNOW WATER	4.09	9650.0

MAXIMUM VEG. SOIL WATER (VOL/VOL) 0.1561

MINIMUM VEG. SOIL WATER (VOL/VOL) 0.0107

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FINAL WATER STORAGE AT END OF YEAR 78

LAYER	(INCHES)	(VOL/VOL)
1	9.46	0.0985
SNOW WATER	0.00	

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NGK METALS CORPORATION READING, PA
POND 1 ROD SELECTED ALTERNATIVE
MAY 11, 1994

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BARE GROUND

LAYER 1

VERTICAL PERCOLATION LAYER

THICKNESS	=	6.00 INCHES
POROSITY	=	0.4750 VOL/VOL
FIELD CAPACITY	=	0.3777 VOL/VOL
WILTING POINT	=	0.2648 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.3777 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	0.000007500000 CM/SEC

LAYER 2

VERTICAL PERCOLATION LAYER

THICKNESS	=	6.00 INCHES
POROSITY	=	0.4170 VOL/VOL
FIELD CAPACITY	=	0.0454 VOL/VOL
WILTING POINT	=	0.0200 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.0454 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	0.100000001490 CM/SEC

LAYER 3

VERTICAL PERCOLATION LAYER

THICKNESS	=	12.00 INCHES
POROSITY	=	0.4710 VOL/VOL
FIELD CAPACITY	=	0.3418 VOL/VOL

WILTING POINT	=	0.2099 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.3418 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	0.000042000000 CM/SEC

LAYER 4

LATERAL DRAINAGE LAYER

THICKNESS	=	6.00 INCHES
POROSITY	=	0.4370 VOL/VOL
FIELD CAPACITY	=	0.0624 VOL/VOL
WILTING POINT	=	0.0245 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.0624 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	0.005799999926 CM/SEC
SLOPE	=	1.50 PERCENT
DRAINAGE LENGTH	=	100.0 FEET

LAYER 5

BARRIER SOIL LINER WITH FLEXIBLE MEMBRANE LINER

THICKNESS	=	0.05 INCHES
POROSITY	=	0.4300 VOL/VOL
FIELD CAPACITY	=	0.3663 VOL/VOL
WILTING POINT	=	0.2802 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.4300 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	0.000000100000 CM/SEC
LINER LEAKAGE FRACTION	=	0.00050000

LAYER 6

VERTICAL PERCOLATION LAYER

THICKNESS	=	96.00 INCHES
POROSITY	=	0.4170 VOL/VOL
FIELD CAPACITY	=	0.0454 VOL/VOL
WILTING POINT	=	0.0200 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.0294 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	0.009999999776 CM/SEC

GENERAL SIMULATION DATA

SCS RUNOFF CURVE NUMBER	=	98.00
TOTAL AREA OF COVER	=	28315. SQ FT
EVAPORATIVE ZONE DEPTH	=	9.00 INCHES
UPPER LIMIT VEG. STORAGE	=	4.1010 INCHES

INITIAL VEG. STORAGE	=	2.0651 INCHES
INITIAL SNOW WATER CONTENT	=	0.0000 INCHES
INITIAL TOTAL WATER STORAGE IN SOIL AND WASTE LAYERS	=	9.8609 INCHES

SOIL WATER CONTENT INITIALIZED BY PROGRAM.

CLIMATOLOGICAL DATA

DEFAULT RAINFALL WITH SYNTHETIC DAILY TEMPERATURES AND
SOLAR RADIATION FOR PHILADELPHIA PENNSYLVANIA

MAXIMUM LEAF AREA INDEX	=	0.00
START OF GROWING SEASON (JULIAN DATE)	=	115
END OF GROWING SEASON (JULIAN DATE)	=	296

NORMAL MEAN MONTHLY TEMPERATURES, DEGREES FAHRENHEIT

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
31.20	33.10	41.80	52.90	62.80	71.60
76.50	75.30	68.20	56.50	45.80	35.50

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 74 THROUGH 78

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	4.59	1.88	4.09	3.03	3.85	4.50
	3.67	4.46	4.17	2.76	2.68	3.99
STD. DEVIATIONS	2.53	0.66	1.00	1.51	2.03	2.17
	1.95	2.49	2.07	1.21	2.63	1.78
RUNOFF						
TOTALS	2.830	0.883	2.479	1.700	2.085	2.662
	2.344	2.705	2.432	1.393	1.619	2.557
STD. DEVIATIONS	2.423	0.543	0.856	1.336	1.456	1.737
	1.710	1.813	1.767	0.725	1.975	1.549
EVAPOTRANSPIRATION						
TOTALS	0.966	1.373	1.662	1.401	1.837	1.708
	1.353	1.814	1.604	1.383	0.815	0.973
STD. DEVIATIONS	0.240	0.370	0.412	0.429	0.561	0.578

	0.514	0.849	0.618	0.646	0.396	0.339

LATERAL DRAINAGE FROM LAYER 4

TOTALS	0.0467	0.0682	0.0983	0.0979	0.0963	0.0862
	0.0814	0.0737	0.0645	0.0603	0.0527	0.0499
STD. DEVIATIONS	0.0108	0.0372	0.0587	0.0572	0.0539	0.0460
	0.0414	0.0359	0.0301	0.0270	0.0227	0.0201

PERCOLATION FROM LAYER 5

TOTALS	0.0006	0.0010	0.0014	0.0014	0.0014	0.0012
	0.0012	0.0010	0.0009	0.0008	0.0007	0.0006
STD. DEVIATIONS	0.0002	0.0006	0.0009	0.0009	0.0009	0.0007
	0.0007	0.0006	0.0005	0.0004	0.0004	0.0003

PERCOLATION FROM LAYER 6

TOTALS	0.0001	0.0000	0.0001	0.0001	0.0001	0.0001
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 74 THROUGH 78

	(INCHES)		(CU. FT.)	PERCENT
PRECIPITATION	43.67	(7.930)	103043.	100.00
RUNOFF	25.691	(6.874)	60620.	58.83
EVAPOTRANSPIRATION	16.889	(1.108)	39851.	38.67
LATERAL DRAINAGE FROM LAYER 4	0.8760	(0.4204)	2067.	2.01
PERCOLATION FROM LAYER 5	0.0122	(0.0068)	29.	0.03
PERCOLATION FROM LAYER 6	0.0006	(0.0001)	2.	0.00
CHANGE IN WATER STORAGE	0.213	(0.471)	503.	0.49

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PEAK DAILY VALUES FOR YEARS 74 THROUGH 78

AR360234

	(INCHES)	(CU. FT.)
PRECIPITATION	3.99	9414.7
RUNOFF	3.717	8771.6
LATERAL DRAINAGE FROM LAYER 4	0.0058	13.7
PERCOLATION FROM LAYER 5	0.0001	0.2
HEAD ON LAYER 5	2.5	
PERCOLATION FROM LAYER 6	0.0000	0.0
SNOW WATER	4.09	9650.0

MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.3264
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.1826

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FINAL WATER STORAGE AT END OF YEAR 78

LAYER	(INCHES)	(VOL/VOL)
1	2.33	0.3880
2	0.36	0.0599
3	4.08	0.3402
4	0.71	0.1190
5	0.02	0.4300
6	2.89	0.0301
SNOW WATER	0.00	

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  NGK METALS CORPORATION READING, PA
  POND 1 PROPOSED ALTERNATIVE
  MAY 11, 1994

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                              BARE GROUND

                               LAYER  1
                               --------

                      VERTICAL PERCOLATION LAYER
   THICKNESS                                 =       1.50 INCHES
   POROSITY                                  =       0.4750 VOL/VOL
   FIELD CAPACITY                            =       0.3777 VOL/VOL
   WILTING POINT                             =       0.2648 VOL/VOL
   INITIAL SOIL WATER CONTENT                =       0.3777 VOL/VOL
   SATURATED HYDRAULIC CONDUCTIVITY          =       0.000007500000 CM/SEC


                               LAYER  2
                               --------

             BARRIER SOIL LINER WITH FLEXIBLE MEMBRANE LINER
   THICKNESS                                 =       4.50 INCHES
   POROSITY                                  =       0.4300 VOL/VOL
   FIELD CAPACITY                            =       0.3663 VOL/VOL
   WILTING POINT                             =       0.2802 VOL/VOL
   INITIAL SOIL WATER CONTENT                =       0.4300 VOL/VOL
   SATURATED HYDRAULIC CONDUCTIVITY          =       0.000000100000 CM/SEC
   LINER LEAKAGE FRACTION                    =       0.00050000


                               LAYER  3
                               --------

                      VERTICAL PERCOLATION LAYER
   THICKNESS                                 =       6.00 INCHES
   POROSITY                                  =       0.4170 VOL/VOL
```

FIELD CAPACITY	=	0.0454 VOL/VOL
WILTING POINT	=	0.0200 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.0258 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	0.100000001490 CM/SEC

LAYER 4

VERTICAL PERCOLATION LAYER

THICKNESS	=	96.00 INCHES
POROSITY	=	0.4170 VOL/VOL
FIELD CAPACITY	=	0.0454 VOL/VOL
WILTING POINT	=	0.0200 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.0294 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	0.009999999776 CM/SEC

GENERAL SIMULATION DATA

SCS RUNOFF CURVE NUMBER	=	98.00
TOTAL AREA OF COVER	=	28315. SQ FT
EVAPORATIVE ZONE DEPTH	=	9.00 INCHES
UPPER LIMIT VEG. STORAGE	=	0.7125 INCHES
INITIAL VEG. STORAGE	=	0.5117 INCHES
INITIAL SNOW WATER CONTENT	=	0.0000 INCHES
INITIAL TOTAL WATER STORAGE IN SOIL AND WASTE LAYERS	=	5.4809 INCHES

SOIL WATER CONTENT INITIALIZED BY PROGRAM.

CLIMATOLOGICAL DATA

DEFAULT RAINFALL WITH SYNTHETIC DAILY TEMPERATURES AND SOLAR RADIATION FOR PHILADELPHIA PENNSYLVANIA

MAXIMUM LEAF AREA INDEX	=	0.00
START OF GROWING SEASON (JULIAN DATE)	=	115
END OF GROWING SEASON (JULIAN DATE)	=	296

NORMAL MEAN MONTHLY TEMPERATURES, DEGREES FAHRENHEIT

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
31.20	33.10	41.80	52.90	62.80	71.60
76.50	75.30	68.20	56.50	45.80	35.50

AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 74 THROUGH 78

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	4.59	1.88	4.09	3.03	3.85	4.50
	3.67	4.46	4.17	2.76	2.68	3.99
STD. DEVIATIONS	2.53	0.66	1.00	1.51	2.03	2.17
	1.95	2.49	2.07	1.21	2.63	1.78
RUNOFF						
TOTALS	3.683	1.190	2.888	2.154	2.697	3.245
	2.816	3.258	3.028	1.897	2.026	3.236
STD. DEVIATIONS	2.550	0.757	0.910	1.483	1.859	1.801
	1.927	2.081	1.947	0.986	2.283	1.685
EVAPOTRANSPIRATION						
TOTALS	0.907	0.865	1.131	0.930	1.201	1.048
	0.964	1.298	1.047	0.876	0.554	0.737
STD. DEVIATIONS	0.240	0.475	0.192	0.304	0.457	0.497
	0.282	0.566	0.519	0.291	0.346	0.347
PERCOLATION FROM LAYER 2						
TOTALS	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
PERCOLATION FROM LAYER 4						
TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 74 THROUGH 78

	(INCHES)		(CU. FT.)	PERCENT
PRECIPITATION	43.67	(7.930)	[illegible]	100.00

RUNOFF	32.118	(7.647)	75786.	73.55
EVAPOTRANSPIRATION	11.558	(1.367)	27273.	26.47
PERCOLATION FROM LAYER 2	0.0003	(0.0001)	1.	0.00
PERCOLATION FROM LAYER 4	0.0005	(0.0000)	1.	0.00
CHANGE IN WATER STORAGE	-0.007	(0.098)	-18.	-0.02

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PEAK DAILY VALUES FOR YEARS 74 THROUGH 78

	(INCHES)	(CU. FT.)
PRECIPITATION	3.99	9414.7
RUNOFF	3.871	9132.8
PERCOLATION FROM LAYER 2	0.0000	0.0
HEAD ON LAYER 2	1.5	
PERCOLATION FROM LAYER 4	0.0000	0.0
SNOW WATER	4.09	9650.0

MAXIMUM VEG. SOIL WATER (VOL/VOL) 0.4750

MINIMUM VEG. SOIL WATER (VOL/VOL) 0.2368

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FINAL WATER STORAGE AT END OF YEAR 78

LAYER	(INCHES)	(VOL/VOL)
1	0.52	0.3468
2	1.94	0.4300
3	0.15	0.0256
4	2.82	0.0294
SNOW WATER	0.00	

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POND 1 AREA PROPOSED ALTERNATIVE - VARIANT 1
NGK METALS CORPORATION
READING, PA
MAY 3, 1994

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BARE GROUND

LAYER 1

VERTICAL PERCOLATION LAYER

THICKNESS	=	6.00 INCHES
POROSITY	=	0.4300 VOL/VOL
FIELD CAPACITY	=	0.3663 VOL/VOL
WILTING POINT	=	0.2802 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.3663 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	0.000003800000 CM/SEC

LAYER 2

VERTICAL PERCOLATION LAYER

THICKNESS	=	6.00 INCHES
POROSITY	=	0.4170 VOL/VOL
FIELD CAPACITY	=	0.0454 VOL/VOL
WILTING POINT	=	0.0200 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.0454 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	0.100000001490 CM/SEC

LAYER 3

VERTICAL PERCOLATION LAYER

THICKNESS	=	96.00 INCHES
POROSITY	=	0.4170 VOL/VOL
FIELD CAPACITY	=	0.0454 VOL/VOL

WILTING POINT = 0.0200 VOL/VOL
INITIAL SOIL WATER CONTENT = 0.0454 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY = 0.009999999776 CM/SEC

GENERAL SIMULATION DATA

SCS RUNOFF CURVE NUMBER = 98.00
TOTAL AREA OF COVER = 28315. SQ FT
EVAPORATIVE ZONE DEPTH = 9.00 INCHES
UPPER LIMIT VEG. STORAGE = 3.8310 INCHES
INITIAL VEG. STORAGE = 1.8503 INCHES
INITIAL SNOW WATER CONTENT = 0.0000 INCHES
INITIAL TOTAL WATER STORAGE IN
SOIL AND WASTE LAYERS = 6.8286 INCHES

SOIL WATER CONTENT INITIALIZED BY PROGRAM.

CLIMATOLOGICAL DATA

DEFAULT RAINFALL WITH SYNTHETIC DAILY TEMPERATURES AND
SOLAR RADIATION FOR PHILADELPHIA PENNSYLVANIA

MAXIMUM LEAF AREA INDEX = 0.00
START OF GROWING SEASON (JULIAN DATE) = 115
END OF GROWING SEASON (JULIAN DATE) = 296

NORMAL MEAN MONTHLY TEMPERATURES, DEGREES FAHRENHEIT

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
31.20	33.10	41.80	52.90	62.80	71.60
76.50	75.30	68.20	56.50	45.80	35.50

****

AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 74 THROUGH 78

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	4.59	1.88	4.09	3.03	3.85	4.50
	3.67	4.46	4.17	2.76	2.68	3.99
STD. DEVIATIONS	2.53	0.66	1.00	1.51	2.03	2.17
	1.95	2.49	2.07	1.21	2.63	1.78

AR360241

RUNOFF

TOTALS	3.098	1.080	2.845	2.004	2.475	3.118
	2.607	3.113	2.783	1.688	1.853	2.894
STD. DEVIATIONS	2.497	0.609	0.885	1.443	1.629	1.966
	1.751	1.987	1.900	0.828	2.128	1.596

EVAPOTRANSPIRATION

TOTALS	0.964	1.167	1.235	1.070	1.383	1.315
	1.117	1.373	1.243	1.199	0.580	0.916
STD. DEVIATIONS	0.238	0.449	0.288	0.410	0.345	0.355
	0.463	0.571	0.564	0.571	0.332	0.288

PERCOLATION FROM LAYER 3

TOTALS	0.0187	0.0259	0.0301	0.0281	0.0278	0.0258
	0.0255	0.0245	0.0228	0.0226	0.0211	0.0225
STD. DEVIATIONS	0.0078	0.0118	0.0140	0.0128	0.0124	0.0113
	0.0109	0.0102	0.0093	0.0090	0.0082	0.0097

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 74 THROUGH 78

	(INCHES)		(CU. FT.)	PERCENT
PRECIPITATION	43.67	(7.930)	103043.	100.00
RUNOFF	29.559	(7.193)	69746.	67.69
EVAPOTRANSPIRATION	13.561	(0.681)	31999.	31.05
PERCOLATION FROM LAYER 3	0.2953	(0.1215)	697.	0.68
CHANGE IN WATER STORAGE	0.255	(0.497)	602.	0.58

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PEAK DAILY VALUES FOR YEARS 74 THROUGH 78

	(INCHES)	(CU. FT.)
PRECIPITATION	3.99	9414.7
RUNOFF	3.832	9042.7

AR360242

PERCOLATION FROM LAYER 3	0.0015	3.5
SNOW WATER	4.09	9650.0

MAXIMUM VEG. SOIL WATER (VOL/VOL) 0.3042

MINIMUM VEG. SOIL WATER (VOL/VOL) 0.1901

****

****

FINAL WATER STORAGE AT END OF YEAR 78

LAYER	(INCHES)	(VOL/VOL)
1	2.16	0.3599
2	0.28	0.0468
3	5.46	0.0569
SNOW WATER	0.00	

****
****

ATTACHMENT 6

DUNN CORPORATION

Engineers, Geologists, Environmental Scientists
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Mechanicsburg, Pennsylvania 17055
Tel: 717/795-8001
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RCRA CORRECTIVE MEASURES STUDY

SUMMERS MODEL

NGK METALS CORPORATION
READING FACILITY

Prepared for:

NGK METALS CORPORATION
READING FACILITY
READING, PENNSYLVANIA 19612

Prepared by:

DUNN CORPORATION
2 MARKET PLAZA WAY
MECHANICSBURG, PENNSYLVANIA 17055

Date:

FEBRUARY 21, 1992

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1.0 INTRODUCTION

At the request of U.S. EPA Region III, the Summers Model was used to predict the concentrations of metals expected to leach from the soil and waste materials at each of the Solid Waste Management Units (SWMU) identified at the NGK facility. This model allows the use of specific analyses for metals and relate these results to the EP Toxicity results. From these actual numbers the model predicts the concentrations that can be expected to leach into the groundwater under current conditions. The various numerical values used in the Model were abstracted from the two previously prepared RCRA Facility Investigation (RFI) reports for the facility by DUNN dated November 15, 1990, and October 25, 1991.

2.0 DESCRIPTION OF THE SUMMERS MODEL

The Summers Model is a simple dilution model that predicts chemical concentrations resulting from leaching of a source and mixing of the leachate with the underlying groundwater. The model assumes that a percentage of area rainfall infiltrates the source and generates leachate by desorption of soil contaminants. The resultant chemical concentrations in the leachate are estimated on the basis that the infiltrating water will be in contact with the contaminants for a period of time sufficient for the maximum amount of leaching to occur. It is further assumed that the leachate then mixes completely with groundwater flowing under the source so that the resulting chemical concentration in the groundwater is a simple function of the leachate generation rate, the chemical concentration in the leachate, and the rate of groundwater flow under the source.

The equation that represents the Summers Model used in the assessment is:

$$C_{gw} = (Q_p \times C_p) / (Q_p + Q_{gw})$$

where: C_{gw} = Resultant chemical concentration in groundwater (μg/l)

Q_p = Volumetric flow rate of infiltration into groundwater (ft^3/day)

Q_{gw} = Volumetric flow rate of groundwater under the source (ft^3/day)

C_p = Chemical concentration in the leachate (μg/l).

A value for the variable C_p was the actual EP Toxicity results or was estimated from:

$$C_p = C_s / K_d$$

where: C_s = Chemical concentration in soil (μg/kg)

K_d = Chemical partition coefficient in soil (mg/kg per mg/l).

2.1 Estimation of a Value for the Variable Q_{gw}

In the Summers Model Q_{gw} is estimated on the basis of the application of Darcy's Law to estimate groundwater flow under the areas of concern. The Darcy equation requires the hydraulic conductivity, the hydraulic gradient, and the cross-sectional area of the aquifer under the SWMU area of the land under investigation. These values are known from the analysis of pump tests recently performed at the site.

A pump test was conducted on MW-9A (November 15, 1990) while wells MW-5A, MW-5B, MW-10A, MW-10B, MW-12A, and MW-12B were monitored for water level response. Later, other pump tests (October 25, 1991) were conducted using wells MW-19 while monitoring responses in wells MW-9A, MW-9B, MW-18, MW-20 and

using well MW-15A and monitoring responses in well MW-22. These tests provided the values for hydraulic conductivity (k), hydraulic gradient (i) in some cases, and the velocity. The static water table values were used for gradient determination. The specific numbers for model variables are listed on the individual summary tables for each area (Tables 1 and 2). In areas which were not involved with the actual pump tests the hydraulic gradient was calculated based on the difference in water levels of well (Δh) divided by the distance between the wells (Δl).

2.2 Estimation of Q_p

The amount of leachate generated by a SWMU (Q_p) is the product of the surface area over which contaminated soil occurs times the annual infiltration rate. To determine the exact infiltration rate at each site, the precipitation rates were compared to the rates calculated from the falling head test results (November 15, 1990). In all but two cases the falling head values produced volumes in excess of precipitation volumes. The exact value used is indicated on the individual summary tables for each SWMU. The precipitation value of 16 inches was used (p. 5-1, November 15, 1990).

2.3 Estimation of a Value for the Variable K_d

The absorption of inorganics is influenced by clay mineralogy and water chemistry. K_d represents the value of the equilibrium partition coefficient for each inorganic compound. The values of K_d were estimated by computing the ratio of the actual soil concentration of the particular inorganic compound to the actual value from the EP Toxicity test result from the same soil interval of the same well then averaging the individual values to obtain one K_d value for each inorganic parameter.

Some inorganics were not in detectable concentrations in the TCLP tests. These concentrations may add together as water flows beneath the upgradient SWMU's to a downgradient SWMU. To check for the resultant concentrations of these low concentration of inorganics the computed K_d values were used. The following is a list of the computed K_d values for each inorganic of interest.

Average K_d Values for Inorganics

Beryllium	1,500	mg/kg
Cadmium	64	"
Chromium	4,300	"
Copper	500	"
Fluoride	112,500	"

2.4 Estimation of Values for the Variable C_S

The C_S variable represents the concentration of inorganics in the soil. Tables 7.1 and 7.2 (November 15, 1990) contain the values of a number of samples within each SMWU. However, in the Model only one value can be used. In each area the largest concentration for each inorganic in each SWMU was used regardless of depth of sample or well. The value is reported in the tables as mg/kg but the Model requires μg/kg. The conversion was obtained by multiplying each value by 1,000.

3.0 EVALUATION OF THE SWMU'S DOWNGRADIENT FROM OTHER SWMU'S

One of the assumption inherent in the Summers Model is that the background contamination concentrations are zero in the groundwater underflowing a SWMU. There are SWMU's situated with respect to the groundwater flow direction (Figure 5-5, November 15, 1990) as to impact other SWMU's.

The Retention Basin and Pond 1 are situated such that flow is to the northeast away from the other SWMU's and each other. Pond 2 is upgradient from the other SWMU's. These areas are considered individually.

For the other areas the groundwater concentration values calculated from each individual SWMU are reported individually and as a group. The calculated values were added to determine exceedence of the MCL values under the downgradient SWMU. The upgradient SWMU's were considered as an entity. No attempt was made to determine what percentage of the upgradient SWMU directly impacted the downgradient SWMU. The following is a list of the SWMU's considered as groups.

- Retention Pond
- Pond 1
- Pond 2
- Pond 3 and upgradient Pond 2
- SE Red Mud Disposal Area and upgradient Pond 2
- SW Red Mud Disposal Area and upgradient Ponds 2 and 3 and SE Red Mud Disposal Area
- Drain Field and upgradient SE Disposal Area
- Pond 6 and upgradient Ponds 2 and 3, and SW Red Mud Disposal Area

4.0 RESULTS

The results of the Summers Model and the groundwater evaluations are presented in Tables 1 and 2 which follow. Each SWMU is tested separately and grouped according to current conditions and if the infiltration rates of certain SWMU's are reduced. On each table the soil monitoring results, actual groundwater concentrations, estimated leachate concentrations calculated from the Summers Model, the comparison criteria (MCL's) and a definitive answer on whether the calculated projections made the by the Model exceed the comparison criteria. Some of the predicted values do exceed the MCL's in some SWMU's if the infiltration rate is not reduced. Table 3 compares the SWMU's under current conditions and if the amount of infiltration for some SWMU's are reduced.

The results will be used in evaluating the corrective measures to be used on the NGK property.

TABLE 1
LEACHATE CONCENTRATIONS
CURRENT CONDITIONS

SWMU: Retention Basin

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	1030000	661	1432.29		
Cadmium	1000	31.8	8.51	5	YES
Chromium,total	47100	188.6	2.41	100	NO
Copper	469000	74.1	16.38	1000	NO
Fluoride	589000	5.8	1.16	2000	NO

VARIABLE VALUES	
Infiltration (inches/yr)	16
As=SWMU contaminated soil area (Square Feet)	18400
SWMU Precipitation volume (Cubic feet/yr)	24533.33
Qp=SWMU Precipitation volume (Cubic feet/day)	67.21
Ax= Cross-sectional area (square feet)	7200.00
K (ft/day)	0.47
i (ft/ft)	0.07
Qgw (clean GW flow under SWMU)(cubic feet/day)	236.88

*Groundwater concentrations (filtered) from Table 6-2,10-25-91,MW-15A

SWMU:Pond 1

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	8190000	19.1	7.17		
Cadmium	577000	5.2	4.92	5	NO
Chromium,total	14700000	286	137.22	100	YES
Copper	191000000	132	38.56	1000	NO
Fluoride	383000	3.1	3.07	2000	NO

VARIABLE VALUES	
Infiltration (Inches/yr)	16
As= SWMU contaminated soil area (Square Feet)	32725
SWMU Precipitation volume (Cubic feet/yr)	43633.33
Qp= SWMU Precipitation volume (Cubic feet/day)	119.54
Ax= Cross-sectional flow area (square feet)	20000
K (ft/day)	0.088
i (ft/ft)	0.007467
Qgw (clean GW flow under SWMU)(cubic feet/day)	13.14

*Groundwater concentrations (filtered) from Table 6-2,10-25-91,MW-11A

TABLE 1
CONTINUED

SWMU:Pond 2

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	2600000	not sampled	1195		
Cadmium	96000	not sampled	649	5	YES
Chromium,total	332000	not sampled	17	100	NO
Copper	7910000	not sampled	4616	1000	YES
Fluoride	1490000	not sampled	6	2000	NO

VARIABLE VALUES	
Infiltration (inches/yr)	16
As= SWMU contaminated soil area (Square Feet)	37700
SWMU infiltration volume (Cubic feet/yr)	32611.33
Qp= SWMU infiltration volume (Cubic feet/day)	89.35
Ax= Cross-sectional area (Square feet)	35000
K (ft/day)	4.00
i (ft/ft)	0.00
Qgw (clean GW flow under SWMU)(cubic feet/day)	100.55

*Groundwater concentrations (filtered) from Table 6-2,10-25-91,MW-20A

SWMU: Pond 3

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	1280000	not sampled	4259.52		
Cadmium	3800	not sampled	28.52	5	YES
Chromium,total	66400	not sampled	0.24	100	NO
Copper	2550000	not sampled	696.68	1000	NO
Fluoride	1070000	not sampled	3.43	2000	NO
Total Organic Carbon	27800000	not sampled			

VARIABLE VALUES	
Infiltration (inches/yr)	16
As= SWMU contaminated soil area (Square Feet)	11550
SWMU Precipitation volume (Cubic feet/yr)	15400.00
Qp= SWMU Precipitation volume (Cubic feet/day)	42.19
Ax= Cross-sectional area (square feet)	26000
K (ft/day)	4
i (ft/ft)	0.00071818
Qgw (clean GW flow under SWMU)(cubic feet/day)	74.69072

*Groundwater concentrations (filtered) from Table 6-2,10-25-91,MW-20A

TABLE 1
CONTINUED

SWMU: Pond 6

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	678000	26.2	26.61		
Cadmium	3800		3.51	5	NO
Chromium,total	48400	350	0.66	100	NO
Copper	11900000	10.2	1402.63	1000	YES
Fluoride	267000	25	0.14	2000	NO

VARIABLE VALUES	
Infiltration (inches/yr)	16
As= SWMU contaminated soil area (Square Feet)	130100
SWMU Precipitation volume (Cubic feet/yr)	173466.67
Qp= SWMU Precipitation volume (Cubic feet/day)	475.25
Ax= Cross-sectional area (square feet)	40000
K (ft/day)	5.20
i (ft/ft)	0.04
Qgw (clean GW flow under SWMU)(cubic feet/day)	7607.39

*Groundwater concentrations (filtered) from Table 6-2,10-25-91,Well 2

SWMU: SW Red Mud Disposal Area

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	10900000	150	46.17		
Cadmium	639000		719.32	5	YES
Chromium,total	552000	797	7.99	100	NO
Copper	16200000		5127.44	1000	YES
Fluoride	4140000	34	2.26	2000	NO

VARIABLE VALUES	
Infiltration (inches/yr)	16
As= SWMU contaminated soil area (Square Feet)	74600
SWMU Precipitation volume (Cubic feet/yr)	99466.67
Qp= SWMU Precipitation volume (Cubic feet/day)	272.51
Ax= Cross-sectional area(square feet)	40000
K (ft/day)	5.2
i (ft/ft)	0.02
Qgw (clean GW flow under SWMU)(cubic feet/day)	4160

*Groundwater concentrations (filtered) from Table 6-2,10-25-91,MW-9A

TABLE 1
CONTINUED

SWMU: SE Red Mud Disposal Area

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	1600000	150	1004.71		
Cadmium	2900		5.88	5	YES
Chromium,total	33500	797	0.28	100	NO
Copper	16500000		599.17	1000	NO
Fluoride	1740000	34	0.56	2000	NO

VARIABLE VALUES	
Infiltration (inches/yr)	16
As= SWMU contaminated soil area (Square Feet)	52900
SWMU Precipitation volume (Cubic feet/yr)	70533.33
Qp= SWMU Precipitation volume (Cubic feet/day)	193.24
Ax= Cross-sectional area (Square feet)	49000
K (ft/day)	5.2
i (ft/ft)	0.02
Qgw (clean GW flow under SWMU)(cubic feet/day)	5096

*Groundwater concentrations (filtered) from Table 6-2,10-25-91,MW-9A

SWMU: Drain Field

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	945000		5.96		
Cadmium	60100		1.50	5	NO
Chromium,total	227000	396	0.09	100	NO
Copper	4910000		16.33	1000	NO
Fluoride	140000	6.1	0.01	2000	NO

VARIABLE VALUES	
Infiltration (inches/yr)	16
As= SWMU contaminated soil area (Square Feet)	36100
SWMU Precipitation volume (Cubic feet/yr)	48133.33
Qp= SWMU Precipitation volume (Cubic feet/day)	131.87
Ax= Cross-sectional flow area (square feet)	33000.00
K (ft/day)	3.9
i (ft/ft)	0.25
Qgw (clean GW flow under SWMU)(cubic feet/day)	32175

*Groundwater concentrations (filtered) from Table 6-2,10-25-91,MW-12A

TABLE 1
CONTINUED

SWMU: Pond 3 & Upgradient Pond 2

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	1280000	not sampled	5454.62		
Cadmium	3800	not sampled	677.82	5	YES
Chromium,total	66400	not sampled	17.17	100	NO
Copper	2550000	not sampled	5312.40	1000	YES
Fluoride	1070000	not sampled	9.66	2000	NO

SWMU: SE Red Mud Disposal Area & Upgradient Pond 2

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	1600000	150	2199.81		
Cadmium	2900		655.19	5	YES
Chromium,total	33500	797	17.22	100	NO
Copper	16500000		5214.89	1000	YES
Fluoride	1740000	34	6.79	2000	NO

SWMU: SW Red Mud Disposal Area & Upgradient Ponds 2 & 3 and SE Red Mud Disposal Area

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	10900000	150	6505.50		
Cadmium	639000		1403.03	5	YES
Chromium,total	552000	797	25.45	100	NO
Copper	16200000		11039.02	1000	YES
Fluoride	4140000	34	12.49	2000	NO

NOTE: Leachate totals are not exact due to rounding.

TABLE 1
CONTINUED

SWMU: Drain Field & Upgradient SE Red Mud Disposal Area

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	945000		1010.67		
Cadmium	60100		7.38	5	YES
Chromium,total	227000	396	0.37	100	NO
Copper	4910000		615.50	1000	NO
Fluoride	140000	6.1	0.57	2000	NO

SWMU: Pond 6 & Upgradient Ponds 2 &3 and SW Red Mud Disposal Area

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	678000	26.2	5527.40		
Cadmium	3800		1400.65	5	YES
Chromium,total	48400	350	25.82	100	NO
Copper	11900000	10.2	11842.47	1000	YES
Fluoride	267000	25	12.06	2000	NO

NOTE: Leachate totals are not exact due to rounding.

TABLE 2
LEACHATE CONCENTRATIONS
REDUCTION OF INFILTRATION AMOUNTS TO MEET MCL'S

SWMU: Retention Basin

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	1030000	661	840.16		
Cadmium	1000	31.8	4.99	5	NO
Chromium,total	47100	188.6	1.41	100	NO
Copper	469000	74.1	9.61	1000	NO
Fluoride	589000	5.8	0.68	2000	NO

VARIABLE VALUES	
Infiltration (inches/yr)	8.4
As=SWMU contaminated soil area (Square Feet)	18400
SWMU Precipitation volume (Cubic feet/yr)	12880.00
Qp=SWMU Precipitation volume (Cubic feet/day)	35.29
Ax= Cross-sectional area (square feet)	7200.00
K (ft/day)	0.47
i (ft/ft)	0.07
Qgw (clean GW flow under SWMU)(cubic feet/day)	236.88

*Groundwater concentrations (filtered) from Table 6-2,10-25-91,MW-15A

SWMU:Pond 1

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	8190000	19.1	5.19		
Cadmium	577000	5.2	3.56	5	NO
Chromium,total	14700000	286	99.35	100	NO
Copper	191000000	132	27.92	1000	NO
Fluoride	383000	3.1	2.22	2000	NO

VARIABLE VALUES	
Infiltration (inches/yr)	3.3
As= SWMU contaminated soil area (Square Feet)	32725
SWMU Precipitation volume (Cubic feet/yr)	8999.38
Qp= SWMU Precipitation volume (Cubic feet/day)	24.66
Ax= Cross-sectional flow area (square feet)	20000
K (ft/day)	0.088
I (ft/ft)	0.007467
Qgw (clean GW flow under SWMU)(cubic feet/day)	13.14

*Groundwater concentrations (filtered) from Table 6-2,10-25-91,MW-11A

TABLE 2
CONTINUED

SWMU:Pond 2

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	2600000	not sampled	2		
Cadmium	96000	not sampled	1	5	NO
Chromium,total	332000	not sampled	0	100	NO
Copper	7910000	not sampled	8	1000	NO
Fluoride	1490000	not sampled	0	2000	NO

VARIABLE VALUES	
Infiltration (inches/yr)	0.01
As= SWMU contaminated soil area (Square Feet)	37700
SWMU infiltration volume (Cubic feet/yr)	31.42
Qp= SWMU infiltration volume (Cubic feet/day)	0.09
Ax= Cross-sectional area (Square feet)	35000
K (ft/day)	4.00
i (ft/ft)	0.00
Qgw (clean GW flow under SWMU)(cubic feet/day)	100.55

*Groundwater concentrations from Table 6-2,10-25-91,MW-20A

SWMU: Pond 3

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	1280000	not sampled	41.51		
Cadmium	3800	not sampled	0.28	5	NO
Chromium,total	66400	not sampled	0.00	100	NO
Copper	2550000	not sampled	6.79	1000	NO
Fluoride	1070000	not sampled	0.03	2000	NO

VARIABLE VALUES	
Infiltration (inches/yr)	0.1
As= SWMU contaminated soil area (Square Feet)	11550
SWMU Precipitation volume (Cubic feet/yr)	96.25
Qp= SWMU Precipitation volume (Cubic feet/day)	0.26
Ax= Cross-sectional area (square feet)	26000
K (ft/day)	4
i (ft/ft)	0.00
Qgw (clean GW flow under SWMU)(cubic feet/day)	74.69

*Groundwater concentrations (filtered) from Table 6-2,10-25-91,MW-20A

TABLE 2
CONTINUED

SWMU: SE Red Mud Disposal Area

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	1600000	150	32.55		
Cadmium	2900		0.19	5	NO
Chromium,total	33500	797	0.01	100	NO
Copper	16500000		19.41	1000	NO
Fluoride	1740000	34	0.02	2000	NO

VARIABLE VALUES	
Infiltration (inches/yr)	0.5
As= SWMU contaminated soil area (Square Feet)	52900
SWMU Precipitation volume (Cubic feet/yr)	2204.17
Qp= SWMU Precipitation volume (Cubic feet/day)	6.04
Ax= Cross-sectional area (Square feet)	49000
K (ft/day)	5.2
i (ft/ft)	0.02
Qgw (clean GW flow under SWMU)(cubic feet/day)	5096

*Groundwater concentrations (filtered) from Table 6-2,10-25-91,MW-9A

SWMU: SW Red Mud Disposal Area

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	10900000	150	0.15		
Cadmium	639000		2.39	5	NO
Chromium,total	552000	797	0.03	100	NO
Copper	16200000		17.07	1000	NO
Fluoride	4140000	34	0.01	2000	NO

VARIABLE VALUES	
Infiltration (inches/yr)	0.05
As= SWMU contaminated soil area (Square Feet)	74600
SWMU Precipitation volume (Cubic feet/yr)	310.83
Qp= SWMU Precipitation volume (Cubic feet/day)	0.85
Ax= Cross-sectional area(square feet)	40000
K (ft/day)	5.2
i (ft/ft)	0.02
Qgw (clean GW flow under SWMU)(cubic feet/day)	4160

*Groundwater concentrations (filtered) from Table 6-2,10-25-91,MW-9A

TABLE 2
CONTINUED

SWMU: Pond 6

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	678000	26.2	8.67		..
Cadmium	3800		1.14	5	NO
Chromium,total	48400	350	0.21	100	NO
Copper	11900000	10.2	456.79	1000	NO
Fluoride	267000	25	0.05	2000	NO

VARIABLE VALUES	
Infiltration (inches/yr)	5
As= SWMU contaminated soil area (Square Feet)	130100
SWMU Precipitation volume (Cubic feet/yr)	54208.33
Qp= SWMU Precipitation volume (Cubic feet/day)	148.52
Ax= Cross-sectional area (square feet)	40000
K (ft/day)	5.20
i (ft/ft)	0.04
Qgw (clean GW flow under SWMU)(cubic feet/day)	7607.39

*Groundwater concentrations (filtered) from Table 6-2,10-25-91,Well 2

TABLE 2
CONTINUED

SWMU: Pond 3 & Upgradient Pond 2

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	1280000	not sampled	43.69		
Cadmium	3800	not sampled	1.46	5	NO
Chromium,total	66400	not sampled	0.03	100	NO
Copper	2550000	not sampled	15.18	1000	NO
Fluoride	1070000	not sampled	0.04	2000	NO

SWMU: SE Red Mud Disposal Area & Upgradient Pond 2

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	1600000	150	34.72		
Cadmium	2900		1.37	5	NO
Chromium,total	33500	797	0.04	100	NO
Copper	16500000		27.80	1000	NO
Fluoride	1740000	34	0.03	2000	NO

SWMU: SW Red Mud Disposal Area & Upgradient Ponds 2 & 3 and SE Red Mud Disposal Area

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	10900000	150	76.39		
Cadmium	639000		4.04	5	NO
Chromium,total	552000	797	0.07	100	NO
Copper	16200000		51.66	1000	NO
Fluoride	4140000	34	0.07	2000	NO

NOTE: Leachate totals are not exact due to rounding.

TABLE 2
CONTINUED

SWMU: Drain Field & Upgradient SE Red Mud Disposal Area

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	945000		38.51		
Cadmium	60100		1.69	5	NO
Chromium,total	227000	396	0.10	100	NO
Copper	4910000		35.74	1000	NO
Fluoride	140000	6.1	0.02	2000	NO

SWMU: Pond 6 & Upgradient Ponds 2 &3 and SW Red Mud Disposal Area

Parameter	Soil Monitoring Results	Actual Groundwater Concentrations*	Estimated Leachate Concentration	Comparison Criteria (MCLs)	Does the estimated Leachate Concentration exceed the Comparison Criteria?
	ug/kg	ug/l	ug/l	ug/l	
Beryllium	678000	26.2	52.51		
Cadmium	3800		5.00	5	NO
Chromium,total	48400	350	0.27	100	NO
Copper	11900000	10.2	489.04	1000	NO
Fluoride	267000	25	0.10	2000	NO

NOTE: Leachate totals are not exact due to rounding.

TABLE 3

SUMMARY TABLE

SWMU	Current Conditions Exceeds	Model Results	MCL/SCL	Reduction of Infiltration Model Results	Reduce Infiltration Amount to:
Units		ug/l	ug/l	ug/l	inches
Retention Basin	Cadmium	8.51	5	4.99	8.4
Pond 1	Chromium	137.22	100	99.35	Pond 1= 3.3
Pond 2	Cadmium	649	5	1	Pond 2= 0.01
	Copper	4616	1000	8	
Pond 3 and 2 (Upgradient)	Cadmium	677.82	5	1.46	Pond 3= 0.1
	Copper	5312.4	1000	15.18	
SE Red Mud Disposal Area and Pond 2 (Upgradient)	Cadmium	655.19	5	1.37	SE Red Mud Dis.Area= 0.5
	Copper	5214.89	1000	27.8	
SW Disposal Area and Ponds 2 &3,SE Disposal Area (Upgradient)	Cadmium	1403.03	5	4.04	SW Red Mud Dis.Area= 0.05
	Copper	11039.02	1000	51.66	
Drain Field and SE Red Mud Disposal Area (Upgradient)	Cadmium	7.38	5	1.69	Drain Field= No Change
Pond 6 and Ponds 2 & 3, SW Red Mud Disposal Area (Upgradient)	Cadmium	1400.65	5	5	Pond 6= 5
	Copper	11842.47	1000	489.04	

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ATTACHMENT 7

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  NGK METALS CORPORATION-READING, PA
  DRAIN FIELD AREA EXISTING CONDITIONS
  MAY 10, 1994

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                               FAIR GRASS


                                LAYER  1
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                        VERTICAL PERCOLATION LAYER
    THICKNESS                              =     96.00 INCHES
    POROSITY                               =      0.4710 VOL/VOL
    FIELD CAPACITY                         =      0.3418 VOL/VOL
    WILTING POINT                          =      0.2099 VOL/VOL
    INITIAL SOIL WATER CONTENT             =      0.3418 VOL/VOL
    SATURATED HYDRAULIC CONDUCTIVITY       =      0.000125999999 CM/SEC



                          GENERAL SIMULATION DATA
                          -----------------------

    SCS RUNOFF CURVE NUMBER                =      75.00
    TOTAL AREA OF COVER                    =   28315. SQ FT
    EVAPORATIVE ZONE DEPTH                 =      21.00 INCHES
    UPPER LIMIT VEG. STORAGE               =       9.8910 INCHES
    INITIAL VEG. STORAGE                   =       7.0076 INCHES
    INITIAL SNOW WATER CONTENT             =       0.0000 INCHES
    INITIAL TOTAL WATER STORAGE IN
      SOIL AND WASTE LAYERS                =      32.8128 INCHES

                SOIL WATER CONTENT INITIALIZED BY PROGRAM.


                           CLIMATOLOGICAL DATA
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    DEFAULT RAINFALL WITH SYNTHETIC DAILY TEMPERATURES AND
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SOLAR RADIATION FOR PHILADELPHIA PENNSYLVANIA

MAXIMUM LEAF AREA INDEX = 2.00
START OF GROWING SEASON (JULIAN DATE) = 115
END OF GROWING SEASON (JULIAN DATE) = 296

NORMAL MEAN MONTHLY TEMPERATURES, DEGREES FAHRENHEIT

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
31.20	33.10	41.80	52.90	62.80	71.60
76.50	75.30	68.20	56.50	45.80	35.50

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 74 THROUGH 78

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	4.59	1.88	4.09	3.03	3.85	4.50
	3.67	4.46	4.17	2.76	2.68	3.99
STD. DEVIATIONS	2.53	0.66	1.00	1.51	2.03	2.17
	1.95	2.49	2.07	1.21	2.63	1.78
RUNOFF						
TOTALS	0.413	0.005	0.073	0.058	0.085	0.041
	0.257	0.068	0.177	0.008	0.352	0.129
STD. DEVIATIONS	0.903	0.012	0.115	0.129	0.139	0.093
	0.395	0.128	0.396	0.019	0.687	0.199
EVAPOTRANSPIRATION						
TOTALS	0.970	1.490	2.709	3.026	4.163	4.631
	3.849	3.666	2.995	2.068	1.389	1.009
STD. DEVIATIONS	0.246	0.220	0.084	0.336	1.024	1.390
	1.851	1.570	1.504	0.840	0.415	0.192
PERCOLATION FROM LAYER 1						
TOTALS	1.4475	1.5968	1.1167	1.1163	0.8083	0.5764
	0.4575	0.3565	0.2898	0.3831	0.4689	0.9464
STD. DEVIATIONS	1.6792	1.3917	0.6271	0.4405	0.2217	0.1407
	0.1279	0.0940	0.0801	0.3356	0.4086	1.1178

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 74 THROUGH 78

	(INCHES)		(CU. FT.)	PERCENT
PRECIPITATION	43.67	(7.930)	103043.	100.00
RUNOFF	1.667	(1.561)	3933.	3.82
EVAPOTRANSPIRATION	31.964	(2.637)	75422.	73.19
PERCOLATION FROM LAYER 1	9.5642	(3.1013)	22568.	21.90
CHANGE IN WATER STORAGE	0.475	(4.340)	1121.	1.09

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PEAK DAILY VALUES FOR YEARS 74 THROUGH 78

	(INCHES)	(CU. FT.)
PRECIPITATION	3.99	9414.7
RUNOFF	1.573	3710.6
PERCOLATION FROM LAYER 1	0.3173	748.8
SNOW WATER	4.09	9650.0
MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.4473	
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.2094	

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FINAL WATER STORAGE AT END OF YEAR 78

LAYER	(INCHES)	(VOL/VOL)
1	36.09	0.3759
SNOW WATER	0.00	

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NGK METALS CORPORATION READING, PA
DRAIN FIELD PROPOSED ALTERNATIVE
MAY 11, 1994

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BARE GROUND

LAYER 1

LATERAL DRAINAGE LAYER

THICKNESS	=	6.00 INCHES
POROSITY	=	0.4170 VOL/VOL
FIELD CAPACITY	=	0.0454 VOL/VOL
WILTING POINT	=	0.0200 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.0454 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	4.000000000000 CM/SEC
SLOPE	=	1.00 PERCENT
DRAINAGE LENGTH	=	250.0 FEET

LAYER 2

BARRIER SOIL LINER WITH FLEXIBLE MEMBRANE LINER

THICKNESS	=	0.08 INCHES
POROSITY	=	0.4000 VOL/VOL
FIELD CAPACITY	=	0.3560 VOL/VOL
WILTING POINT	=	0.2899 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.4000 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	0.000000010000 CM/SEC
LINER LEAKAGE FRACTION	=	0.00050000

LAYER 3

VERTICAL PERCOLATION LAYER

THICKNESS	=	96.00 INCHES
POROSITY	=	0.4710 VOL/VOL
FIELD CAPACITY	=	0.3418 VOL/VOL
WILTING POINT	=	0.2099 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2099 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	0.000042000000 CM/SEC

GENERAL SIMULATION DATA

SCS RUNOFF CURVE NUMBER	=	90.00
TOTAL AREA OF COVER	=	28315. SQ FT
EVAPORATIVE ZONE DEPTH	=	9.00 INCHES
UPPER LIMIT VEG. STORAGE	=	2.5020 INCHES
INITIAL VEG. STORAGE	=	0.2831 INCHES
INITIAL SNOW WATER CONTENT	=	0.0000 INCHES
INITIAL TOTAL WATER STORAGE IN SOIL AND WASTE LAYERS	=	20.4548 INCHES

SOIL WATER CONTENT INITIALIZED BY PROGRAM.

CLIMATOLOGICAL DATA

DEFAULT RAINFALL WITH SYNTHETIC DAILY TEMPERATURES AND
SOLAR RADIATION FOR PHILADELPHIA PENNSYLVANIA

MAXIMUM LEAF AREA INDEX	=	0.00
START OF GROWING SEASON (JULIAN DATE)	=	115
END OF GROWING SEASON (JULIAN DATE)	=	296

NORMAL MEAN MONTHLY TEMPERATURES, DEGREES FAHRENHEIT

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
31.20	33.10	41.80	52.90	62.80	71.60
76.50	75.30	68.20	56.50	45.80	35.50

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 74 THROUGH 78

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	4.59	1.88	4.09	3.03	3.85	4.50
	3.67	4.46	4.17	2.76	2.68	3.99

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STD. DEVIATIONS	2.53	0.66	1.00	1.51	2.03	2.17
	1.95	2.49	2.07	1.21	2.63	1.78
RUNOFF						
TOTALS	1.404	0.361	1.279	0.869	1.030	1.306
	1.385	1.409	1.263	0.668	0.993	1.275
STD. DEVIATIONS	1.443	0.201	0.486	0.777	0.801	0.937
	1.187	0.967	1.178	0.336	1.362	0.803
EVAPOTRANSPIRATION						
TOTALS	0.739	0.742	1.224	1.188	1.708	2.104
	1.518	1.921	1.461	0.940	0.513	0.681
STD. DEVIATIONS	0.150	0.376	0.262	0.318	0.780	0.781
	0.676	1.020	0.547	0.517	0.222	0.165
LATERAL DRAINAGE FROM LAYER 1						
TOTALS	2.5466	0.9524	1.4098	1.1961	1.0129	1.1105
	0.8204	1.1272	1.3127	1.1430	1.0923	2.0125
STD. DEVIATIONS	1.1642	0.6589	0.3466	0.6348	0.5754	0.6074
	0.6556	0.7232	0.9230	0.5418	0.9287	1.1318
PERCOLATION FROM LAYER 2						
TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
PERCOLATION FROM LAYER 3						
TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 74 THROUGH 78

	(INCHES)		(CU. FT.)	PERCENT
PRECIPITATION	43.67	(7.930)	103043.	100.00
RUNOFF	13.242	(4.196)	31245.	30.32
EVAPOTRANSPIRATION	14.740	(1.183)	34780.	33.75

LATERAL DRAINAGE FROM LAYER 1	15.7364 (3.3206)	37131.	36.03
PERCOLATION FROM LAYER 2	0.0001 (0.0000)	0.	0.00
PERCOLATION FROM LAYER 3	0.0001 (0.0000)	0.	0.00
CHANGE IN WATER STORAGE	-0.048 (0.414)	-114.	-0.11

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PEAK DAILY VALUES FOR YEARS 74 THROUGH 78

	(INCHES)	(CU. FT.)
PRECIPITATION	3.99	9414.7
RUNOFF	2.855	6737.1
LATERAL DRAINAGE FROM LAYER 1	0.7421	1751.1
PERCOLATION FROM LAYER 2	0.0000	0.0
HEAD ON LAYER 2	1.7	
PERCOLATION FROM LAYER 3	0.0000	0.0
SNOW WATER	4.09	9650.0

MAXIMUM VEG. SOIL WATER (VOL/VOL) 0.2260

MINIMUM VEG. SOIL WATER (VOL/VOL) -0.0271

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FINAL WATER STORAGE AT END OF YEAR 78

LAYER	(INCHES)	(VOL/VOL)
1	0.10	0.0160
2	0.03	0.4000
3	20.15	0.2099
SNOW WATER	0.00	

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